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National Aeronautics and
Space Administration

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RELATIVE RESISTANCE TO IGNITION OF SELECTED
TURBOPUMP MATERIALS IN HIGH-PRESSURE,
HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS,
VOLUME 3 Interim Report (NASA) 150 p

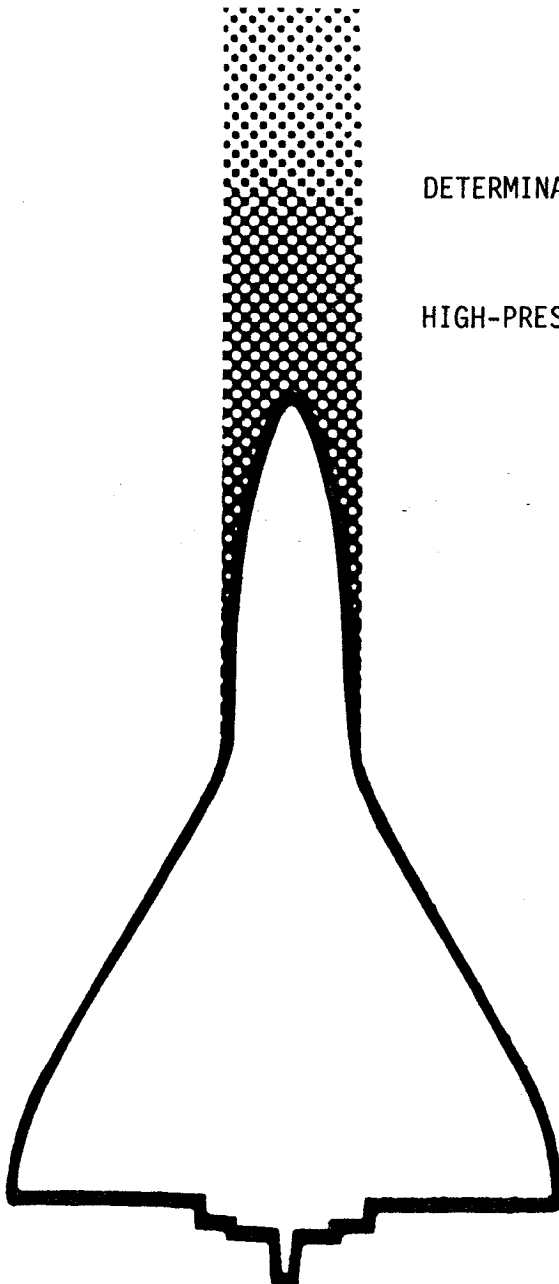
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TEST REPORT

VOLUME III

DETERMINATION OF THE RELATIVE RESISTANCE TO IGNITION
OF SELECTED TURBOPUMP MATERIALS IN
HIGH-PRESSURE, HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS



Lyndon B. Johnson Space Center
White Sands Test Facility
Post Office Drawer MM
Las Cruces, New Mexico 88001
AC 505 524-5011

TEST REPORT
DETERMINATION OF THE RELATIVE RESISTANCE TO IGNITION
OF SELECTED TURBOPUMP MATERIALS IN
HIGH-PRESSURE, HIGH-TEMPERATURE, OXYGEN ENVIRONMENTS

VOLUME III

Issued By
National Aeronautics and Space Administration
Johnson Space Center
White Sands Test Facility
Laboratories Test Office

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ABSTRACT

Advances in the design of the liquid oxygen, liquid hydrogen engines for the Space Transportation System call for the use of warm, high-pressure oxygen as the driving gas in the liquid oxygen turbopump. The NASA Lewis Research Center requested the NASA White Sands Test Facility (WSTF) to design a test program to determine the relative resistance to ignition of nine selected turbopump materials: Hastelloy X, Inconel 600, Invar 36, Monel K-500, Monel 400, nickel 200, silicon carbide, stainless steel 316, and zirconium copper. The materials were subjected to particle impact and to frictional heating in high-pressure oxygen.

In the particle impact tests, nickel 200, Monel 400, and silicon carbide were the most resistant to ignition; Monel K-500 and zirconium copper were slightly less resistant to ignition; and Hastelloy X, Invar 36, and stainless steel 316 were the least resistant to ignition. Inconel 600 was not tested.

In frictional heating tests of pairs of like materials, the ranking was generally upheld, with the materials ranked in order of decreasing resistance to ignition as follows: nickel 200, Inconel 600, Monel 400, Monel K-500, Hastelloy X, Invar 36, and stainless steel 316. Pairs of silicon carbide and zirconium copper failed mechanically at modest contact pressures and did not ignite.

In tests where pairs of different materials were rubbed together, the material rated less resistant to ignition in previous tests appeared to control the resistance to ignition of the pair.

Tests designed to determine the effects of oxygen pressure on the results of frictional heating appeared to indicate that the greater heat rates per unit area required to ignite metals at high pressures resulted from increased convective heat losses from the test samples.

PREFACE

This interim report addresses the test series that resulted from three test plans written at the NASA White Sands Test Facility in response to a request from the NASA Lewis Research Center to determine the relative compatibility of selected turbopump materials in gaseous oxygen. The first test plan, Determination of the Ignition Sensitivity of Selected Turbopump Metals in High Pressure, High Temperature, Oxygen Environments (TP-WSTF-324), proposed tests in which eight materials were impacted with particles in hot, high-pressure oxygen and nine materials were heated frictionally in high-pressure oxygen. The second test plan, TP-WSTF-324 ADDI, proposed tests in which pairs of different materials were rubbed together in high-pressure oxygen to induce frictional heating. The third test plan, Evaluation of Pressure Effects in the WSTF Friction Rubbing Test System (TP-WSTF-356), proposed tests to determine the effects of the test gas pressure on the results of frictional heating tests. Testing proposed in the first and third test plans has been completed, and six of the eight tests proposed in the second test plan have been completed.

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APPENDIX E

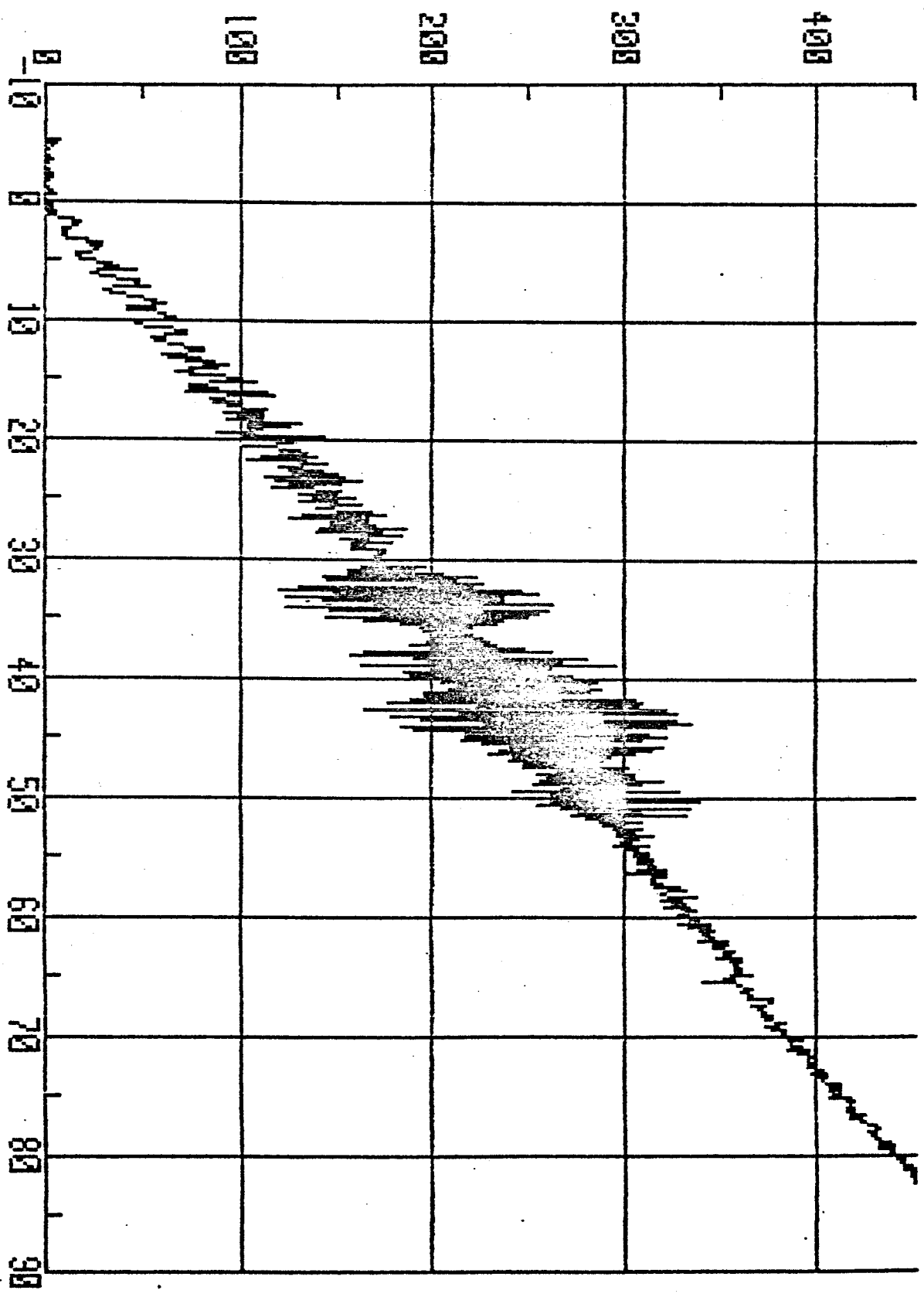
Data From Frictional Heating Tests on Pairs of Different Materials

TEST NUMBER	TEST MATERIAL		PAGE
	ROTATING SAMPLE	STATIONARY SAMPLE	
252	Monel K-500	Monel K-500	E-1
255			E-9
256			E-17
257	Stainless Steel 316	Zirconium Copper	E-25
258			E-33
259			E-41
260	Stainless Steel 316	Monel K-500	E-49
261			E-57
262			E-65
263	Silicon Carbide	Invar 36	E-73
264			E-81
265			E-89
266	Silicon Carbide	Monel K-500	E-97
267			E-105
268			E-113
272	Monel K-500	Nickel (EP)	E-121
273			E-129
274			E-137

FRT#252: Mon. K500-Stat.; Mon. K500-Rot.

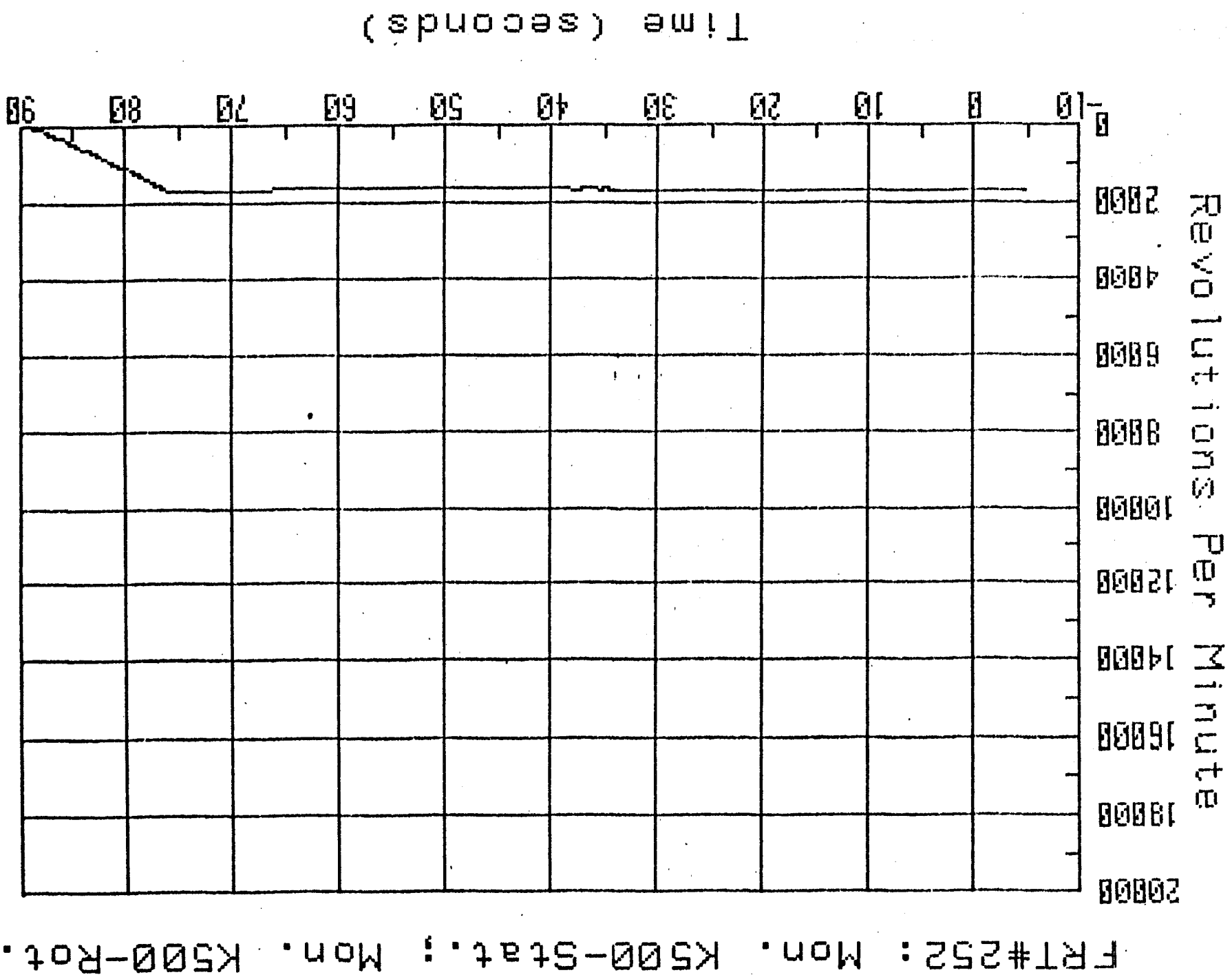
E-1

Normal Load (Lbf)

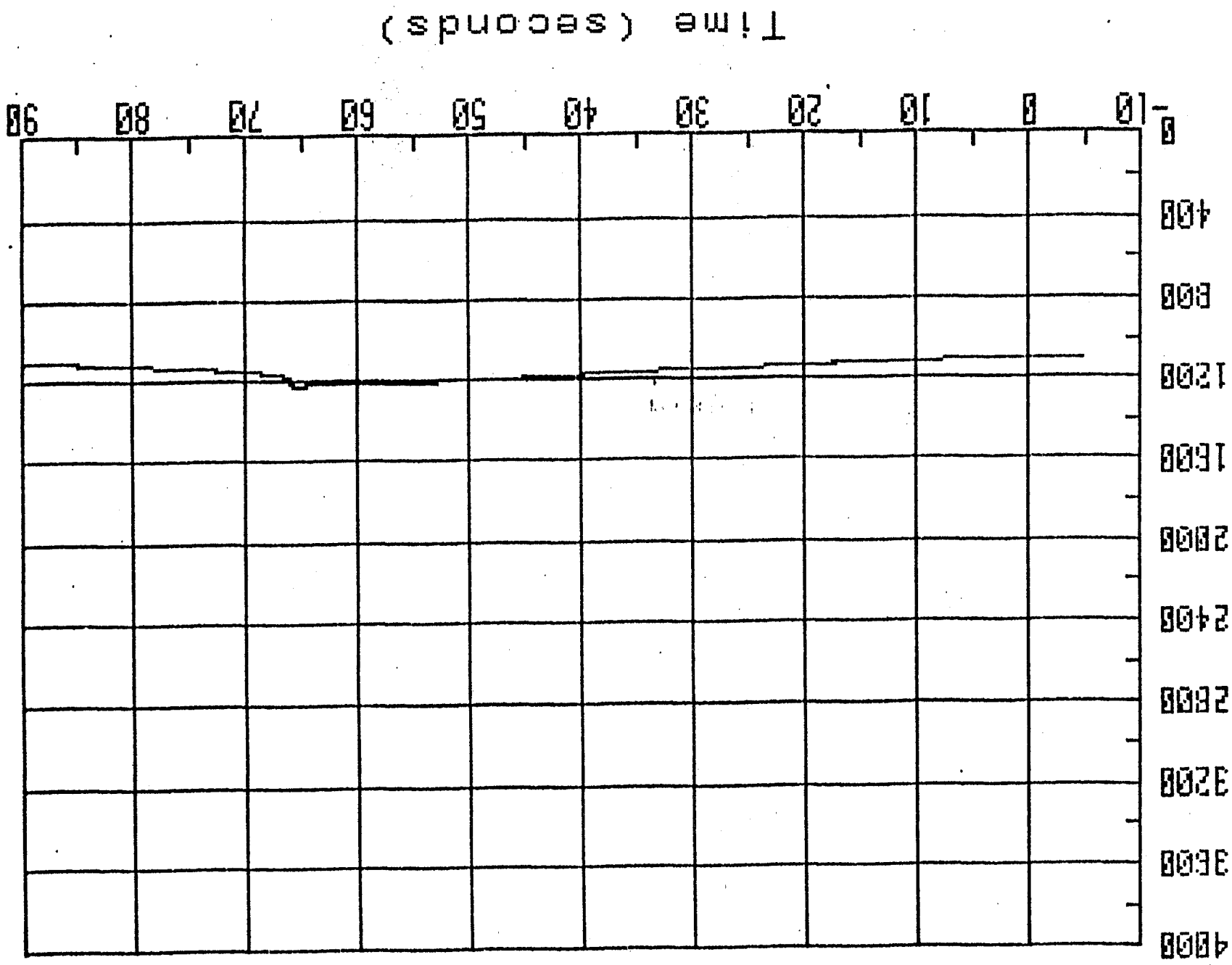


Time (seconds)

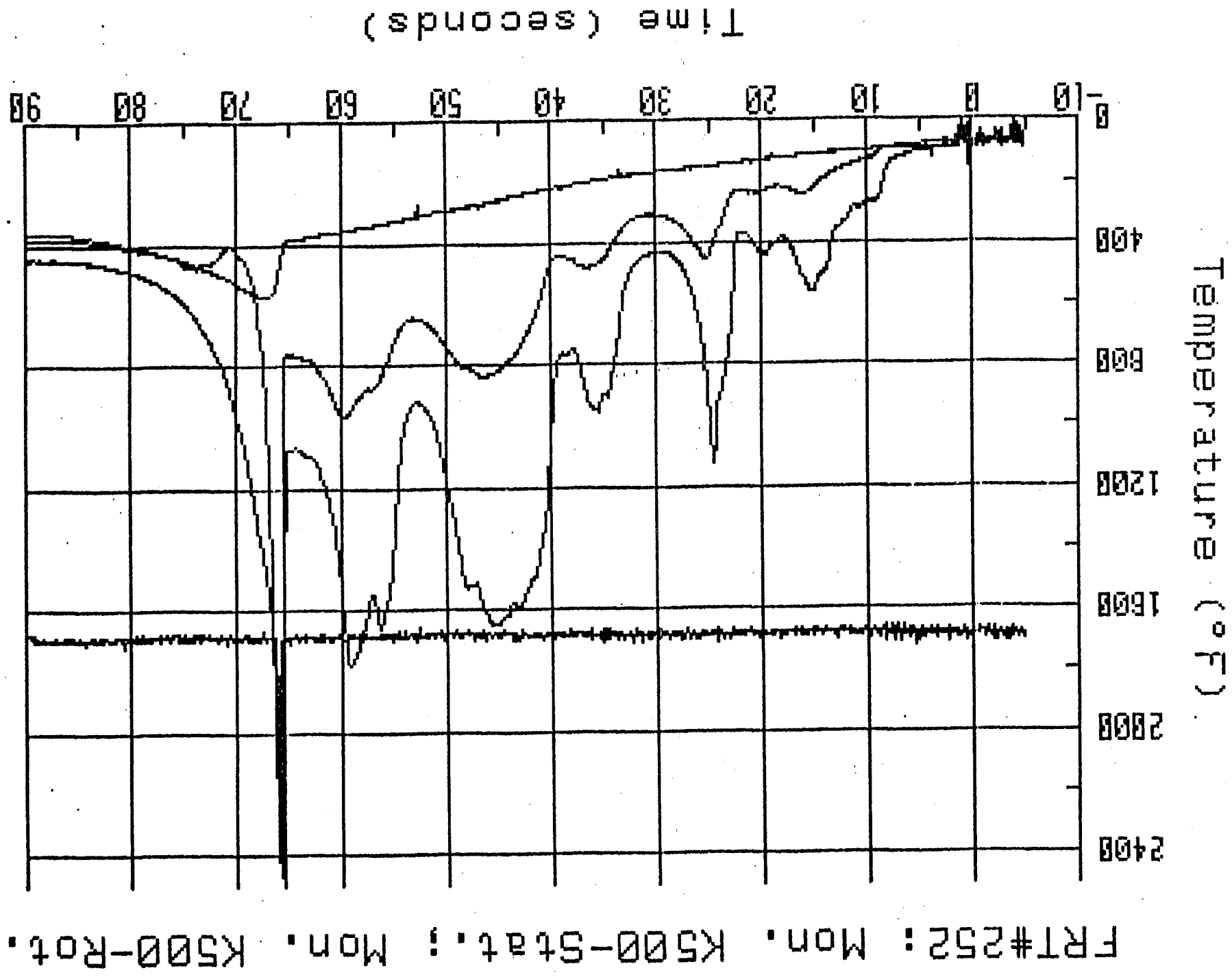
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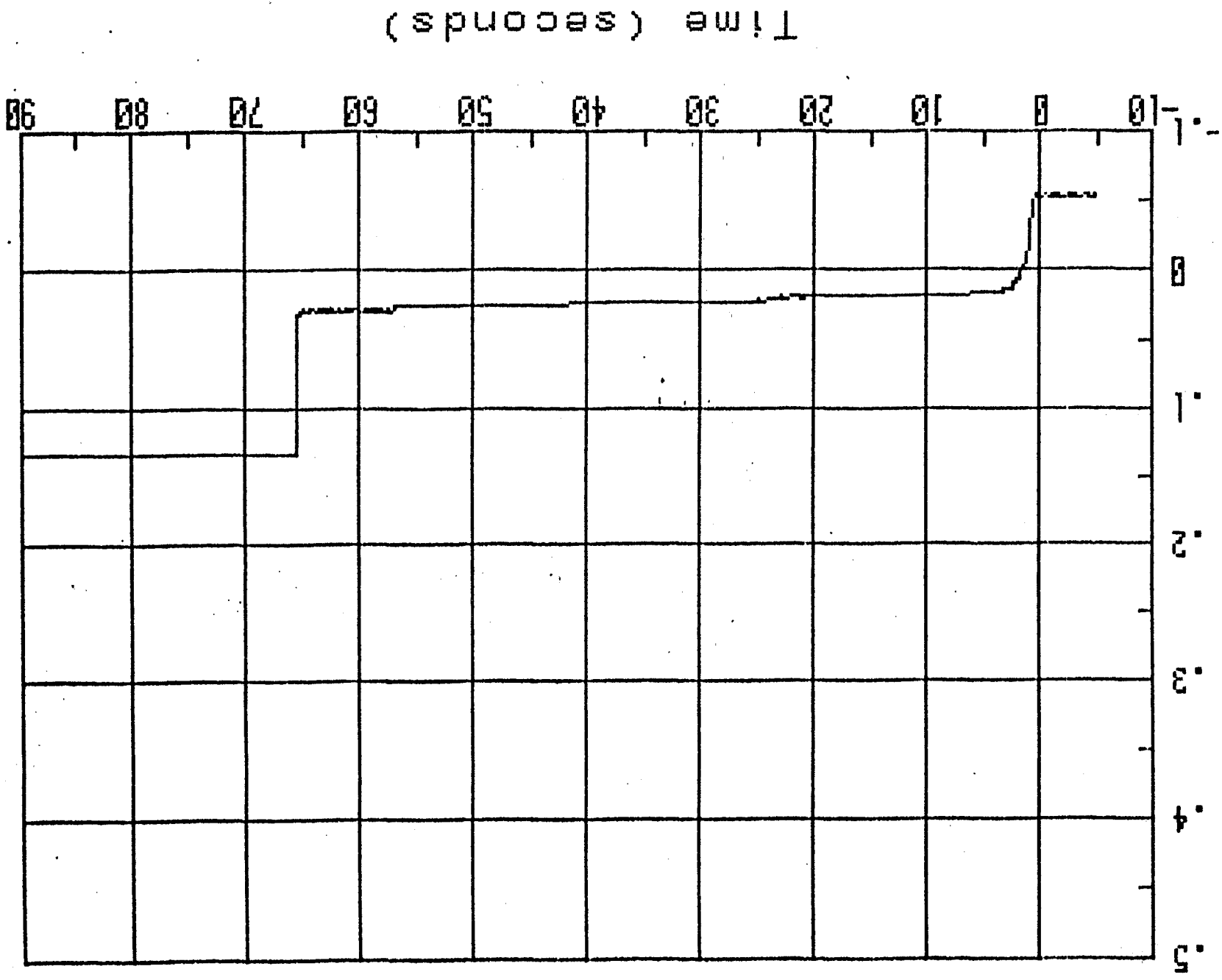
Chamber Oxygen Pressure (PSIG)



FRT#252: Mon. K500-Stat.; Mon. K500-Rot.



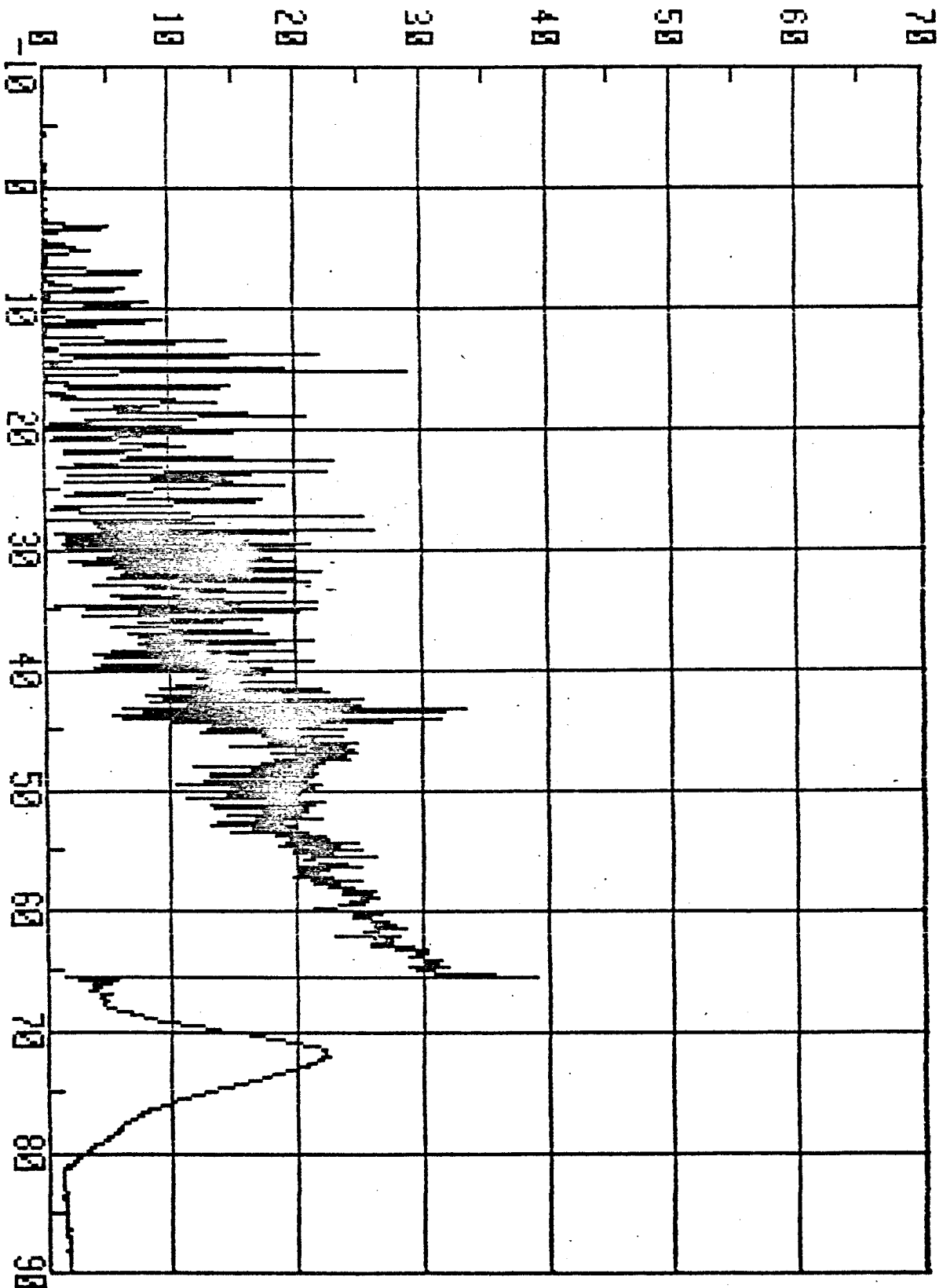
Sample Wear (Inches)



FRT#252: Mon. K500-Stat.; Mon. K500-Rot.

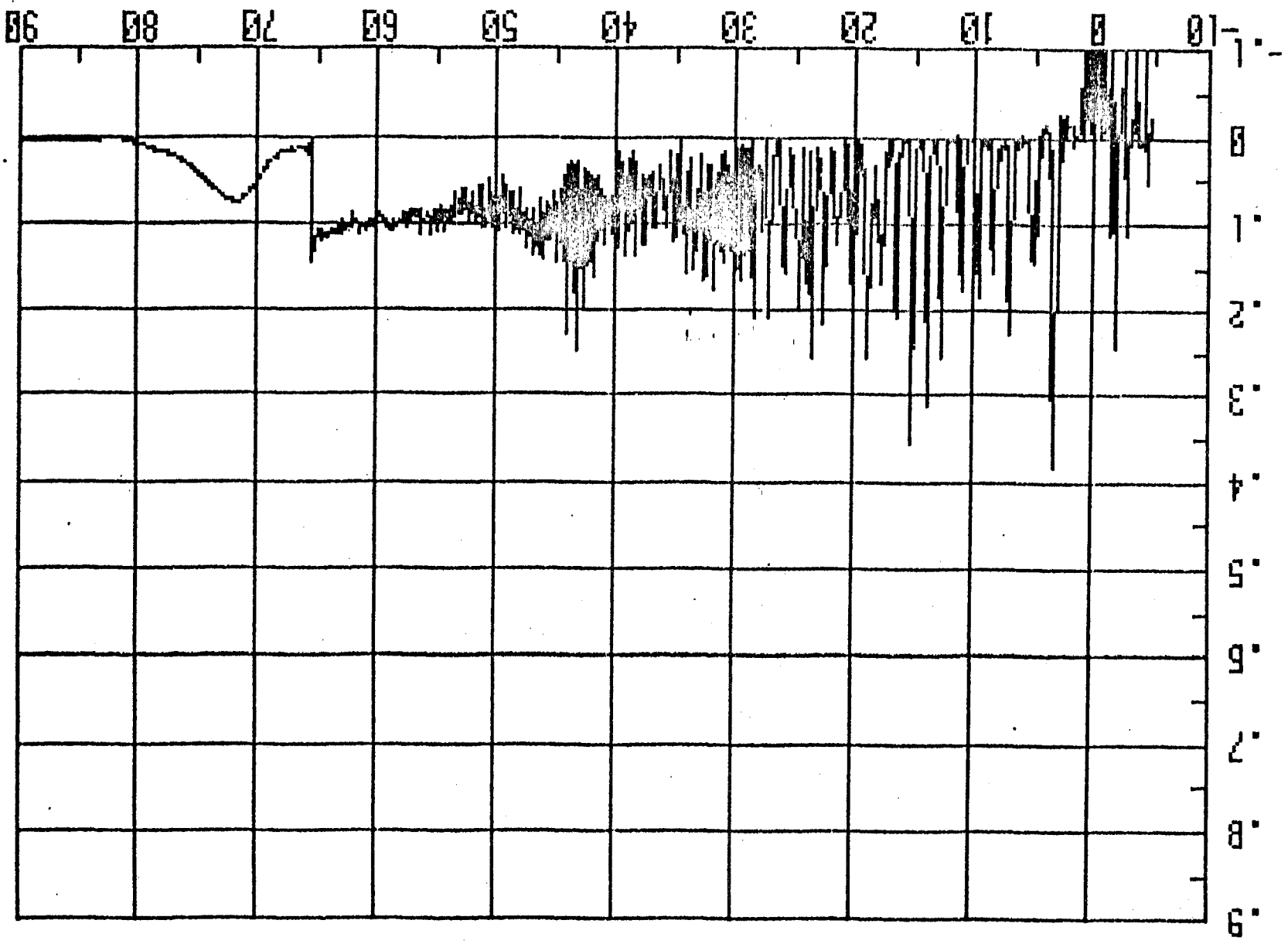
Torque Load (Lbf)

FRT#252: Mon. K500-Stat.; Mon. K500-Rot.



Time (seconds)

Coefficient of Friction

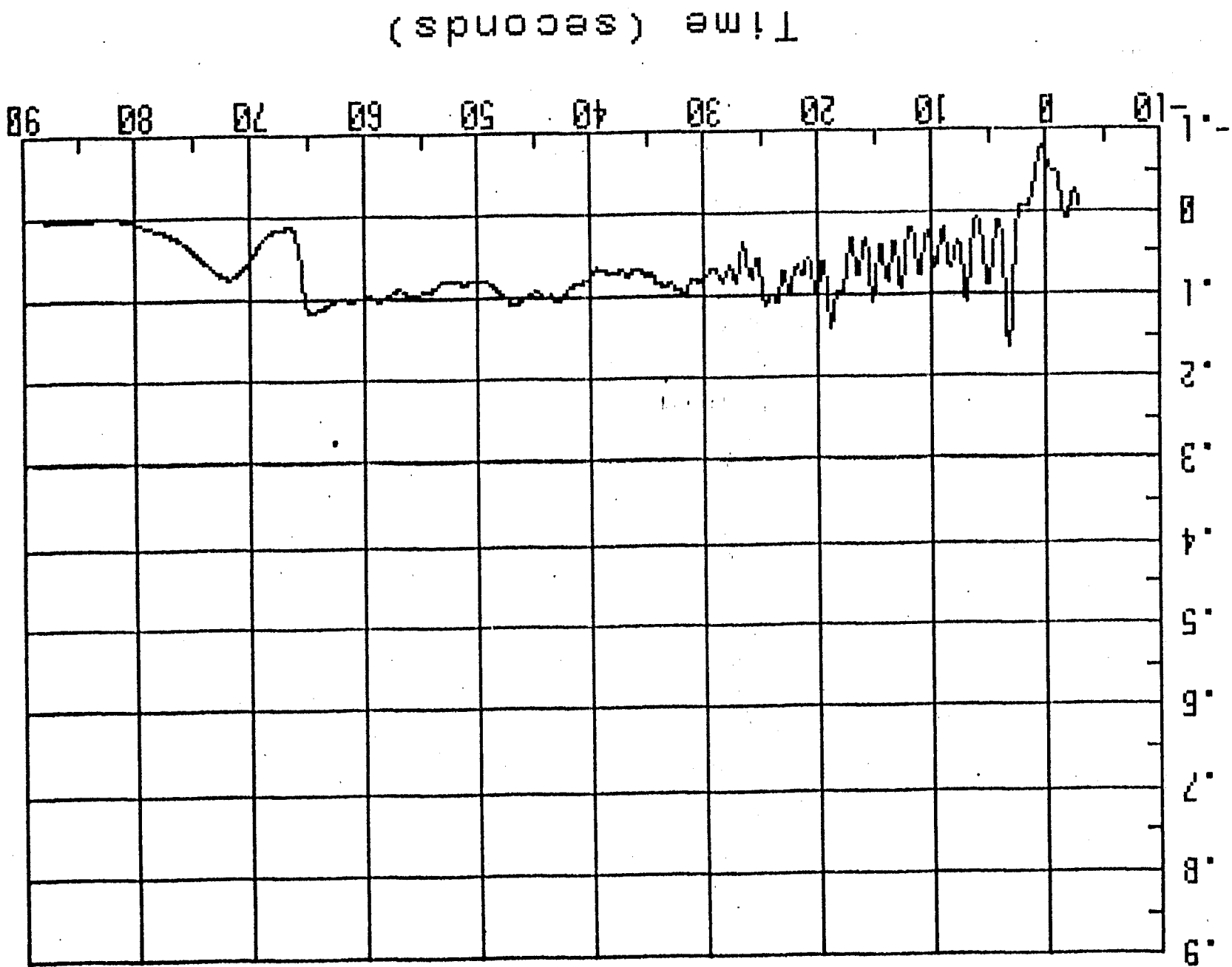


FRT#252: Mon. K500-Stat.: Mon. K500-Rot.

Time (seconds)

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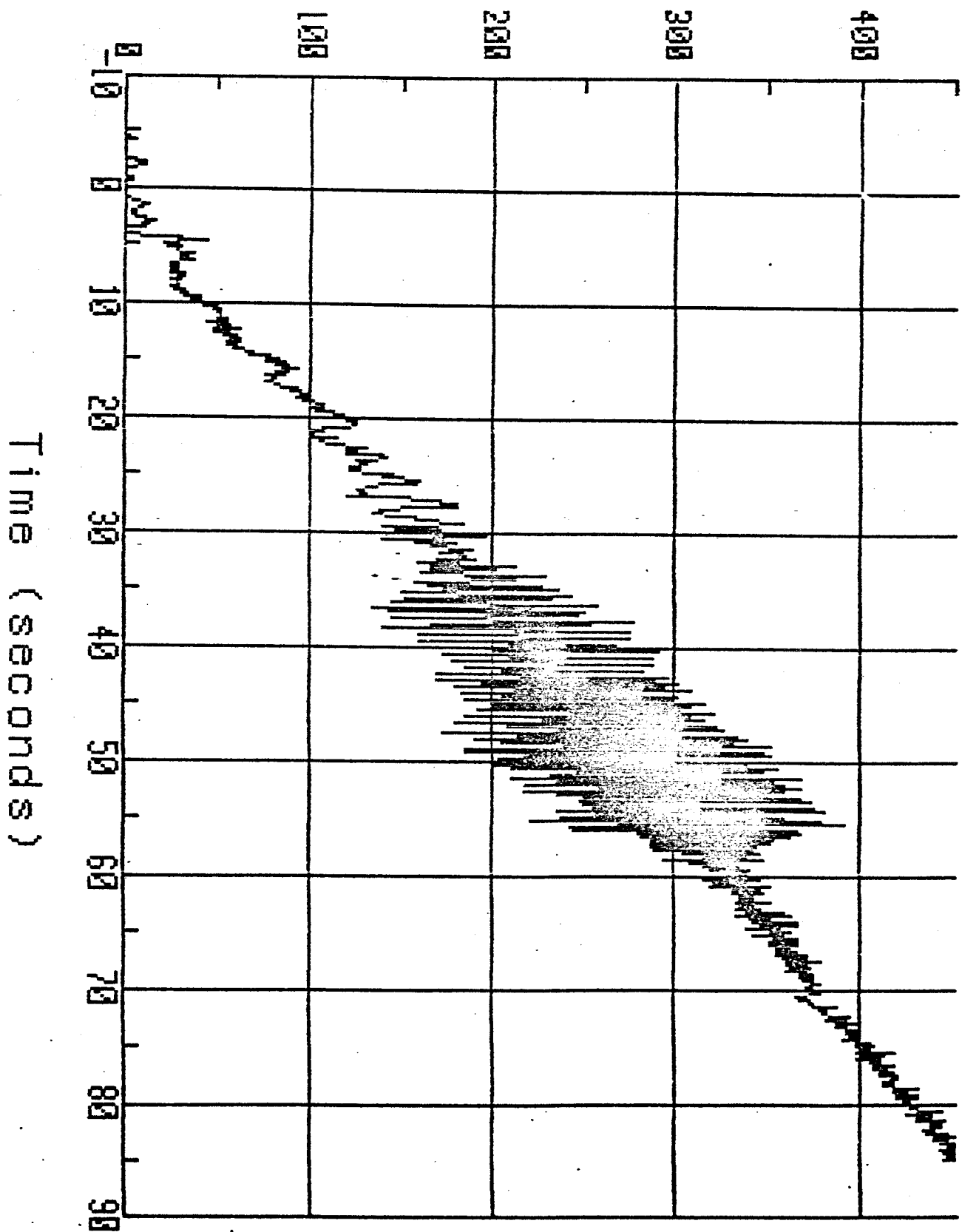
Filtered Coefficient of Friction

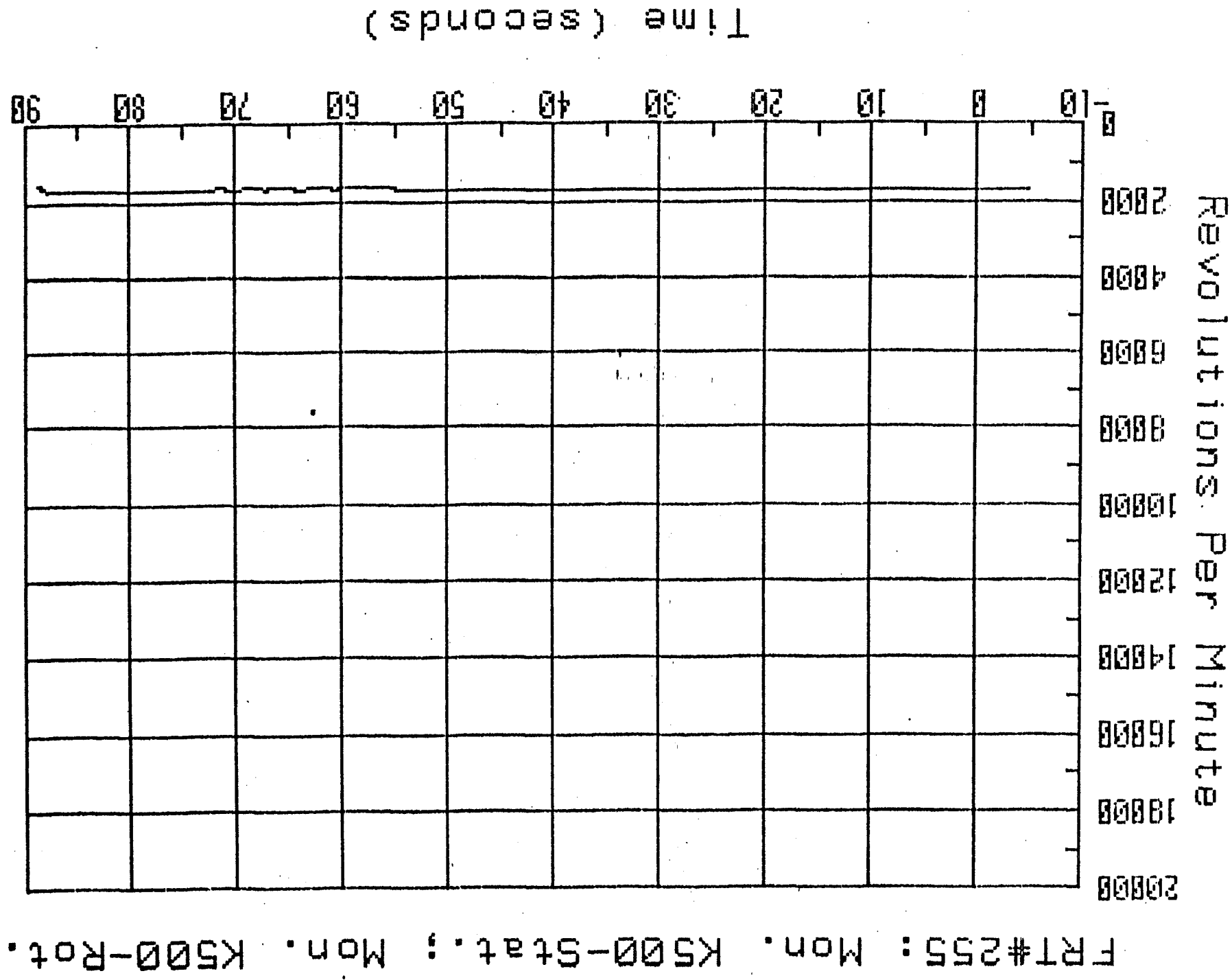


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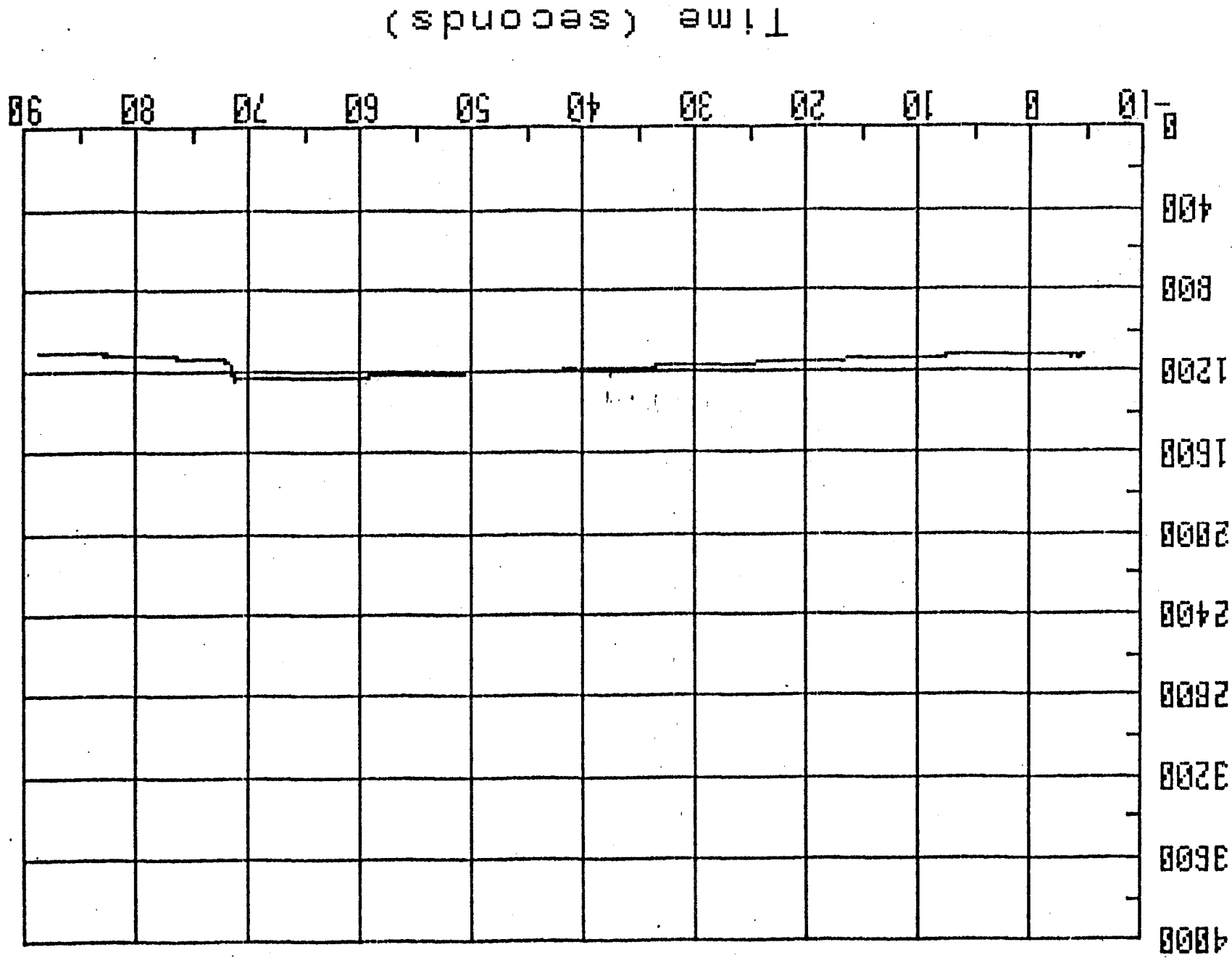
Normal Load (Lbf)





11-3

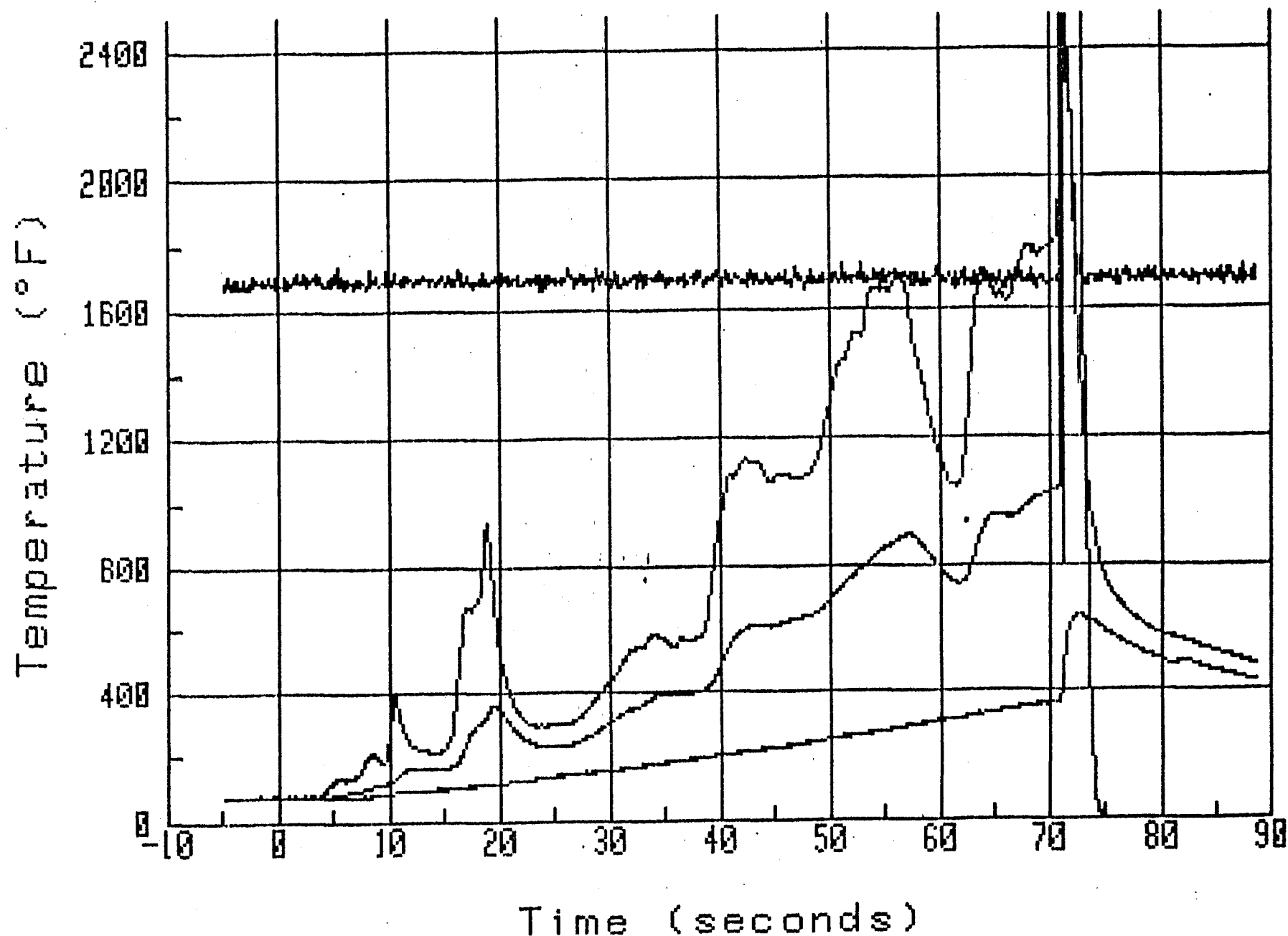
Chamber Oxygen Pressure (PSIG)



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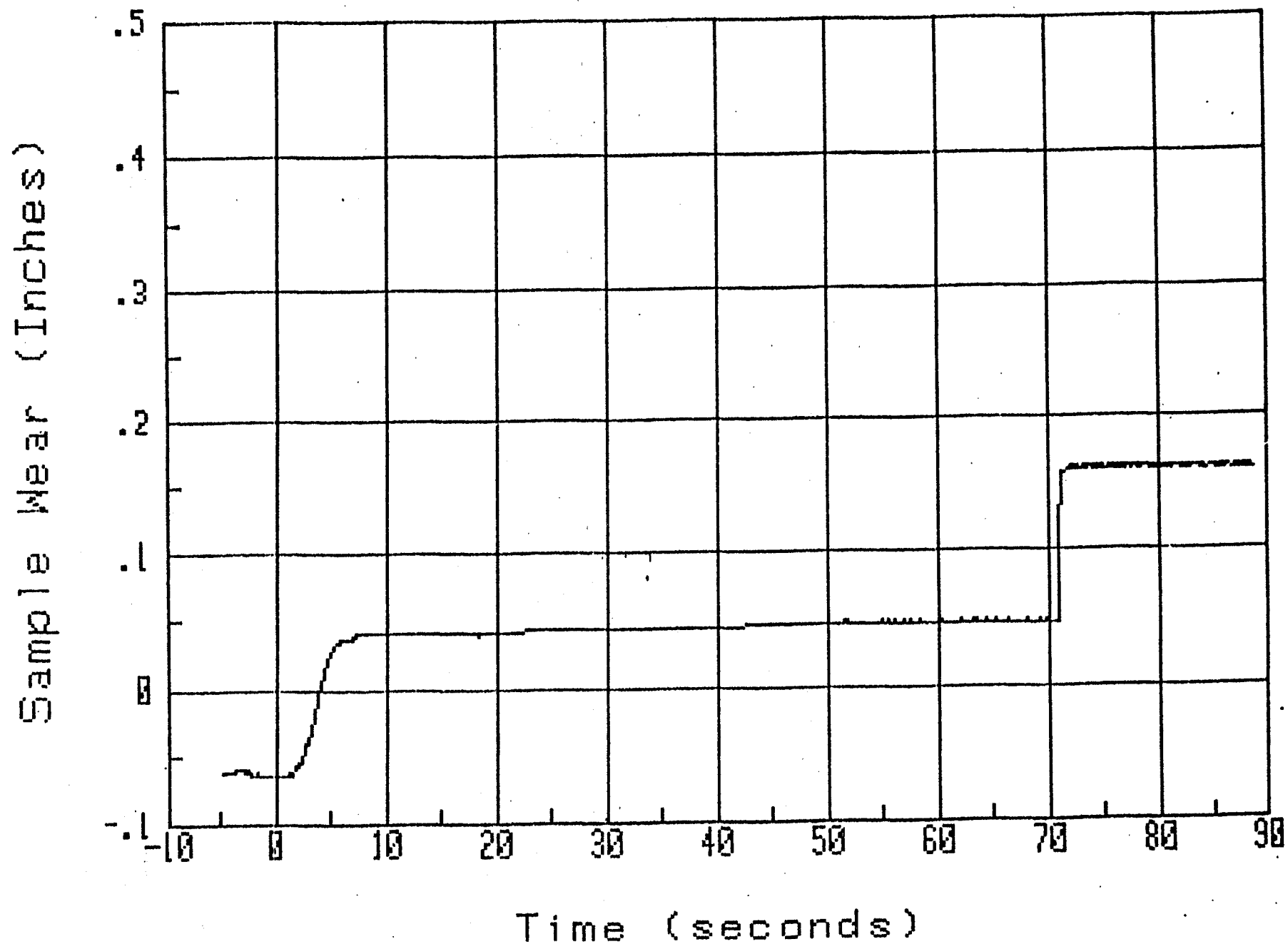
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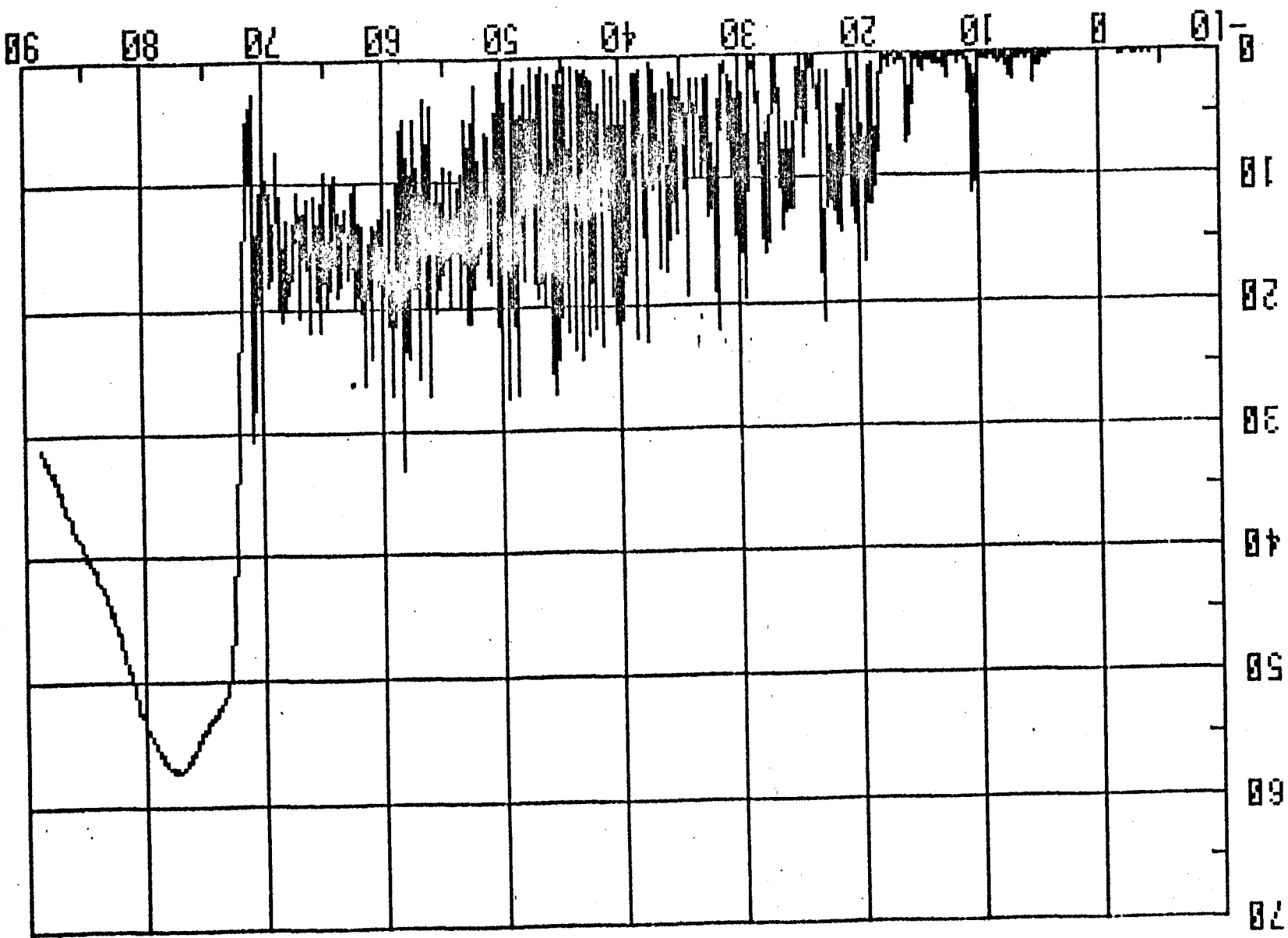


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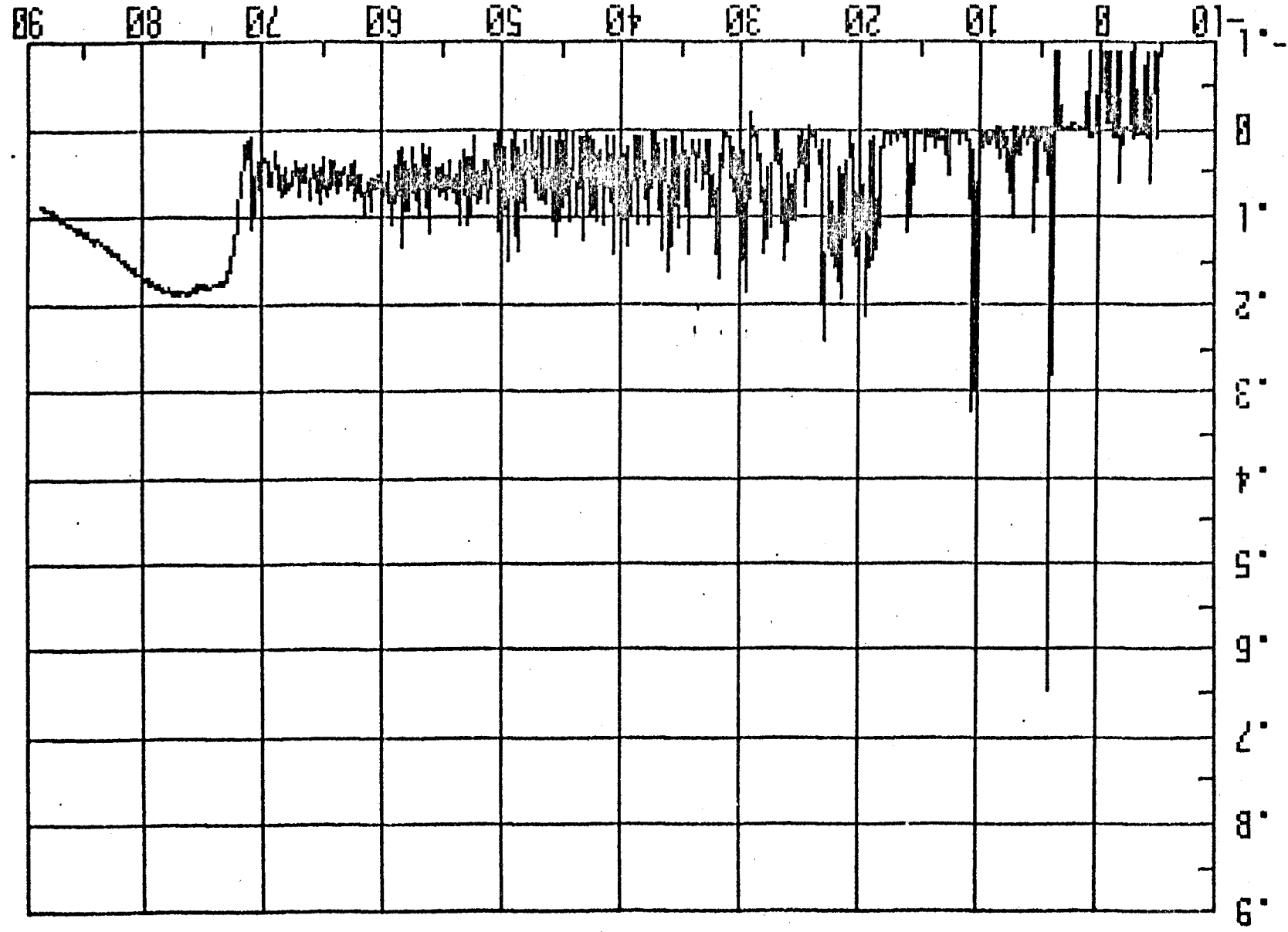


Torque Load (Lbf)



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Coefficient of Friction



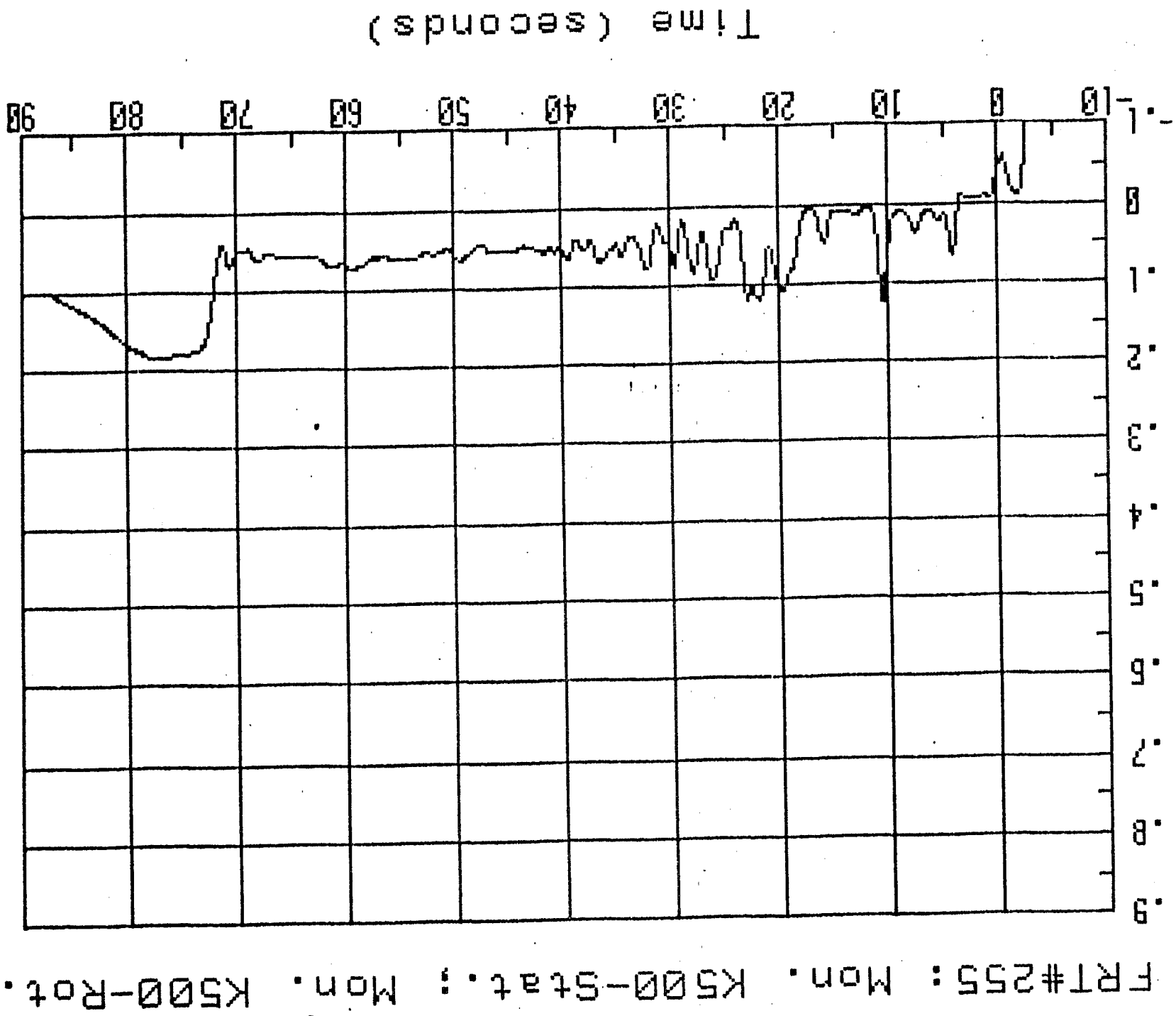
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Contains a torque load and a normal load offset.

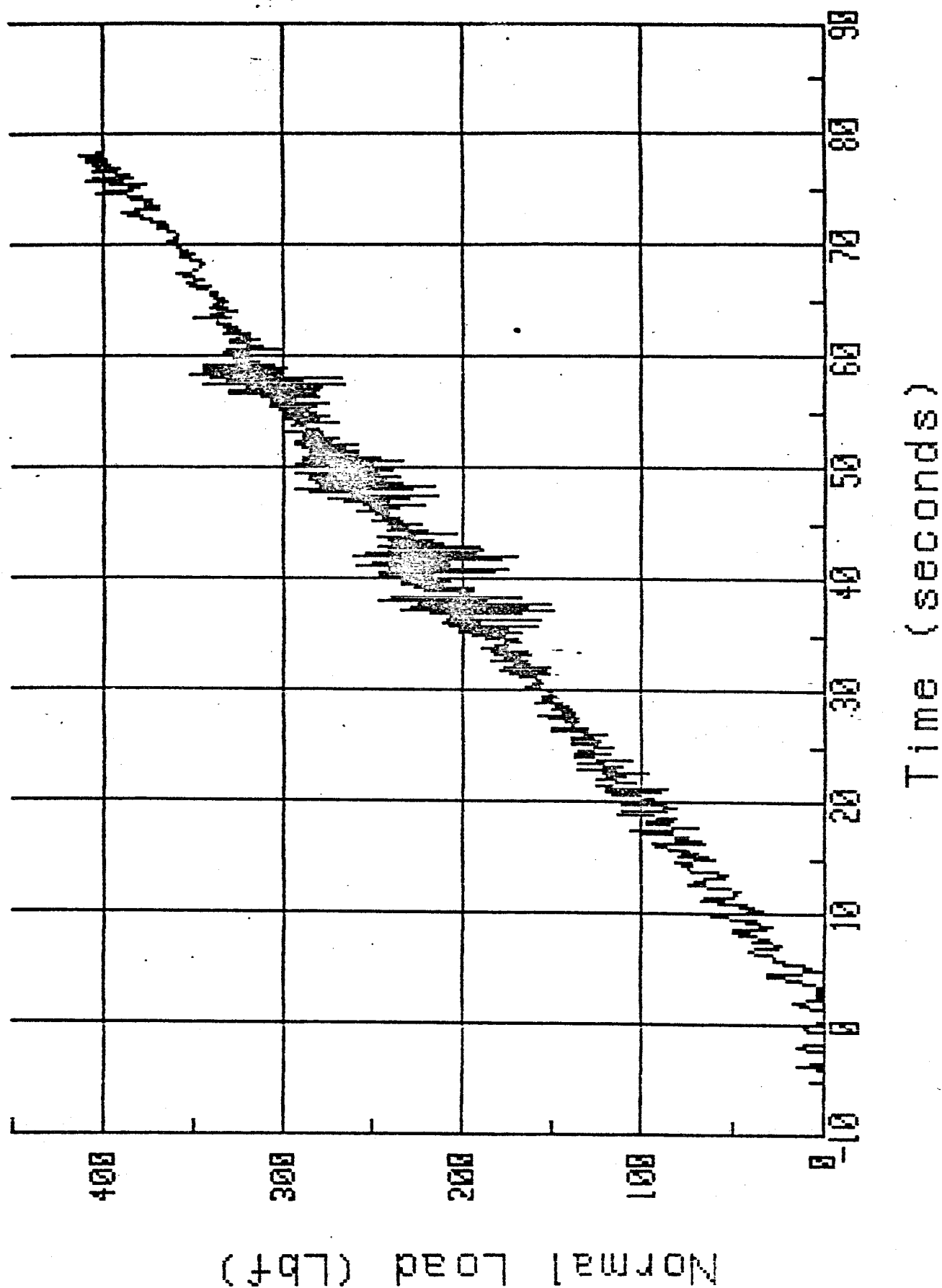
Time (seconds)

Filtered Coefficient of Friction

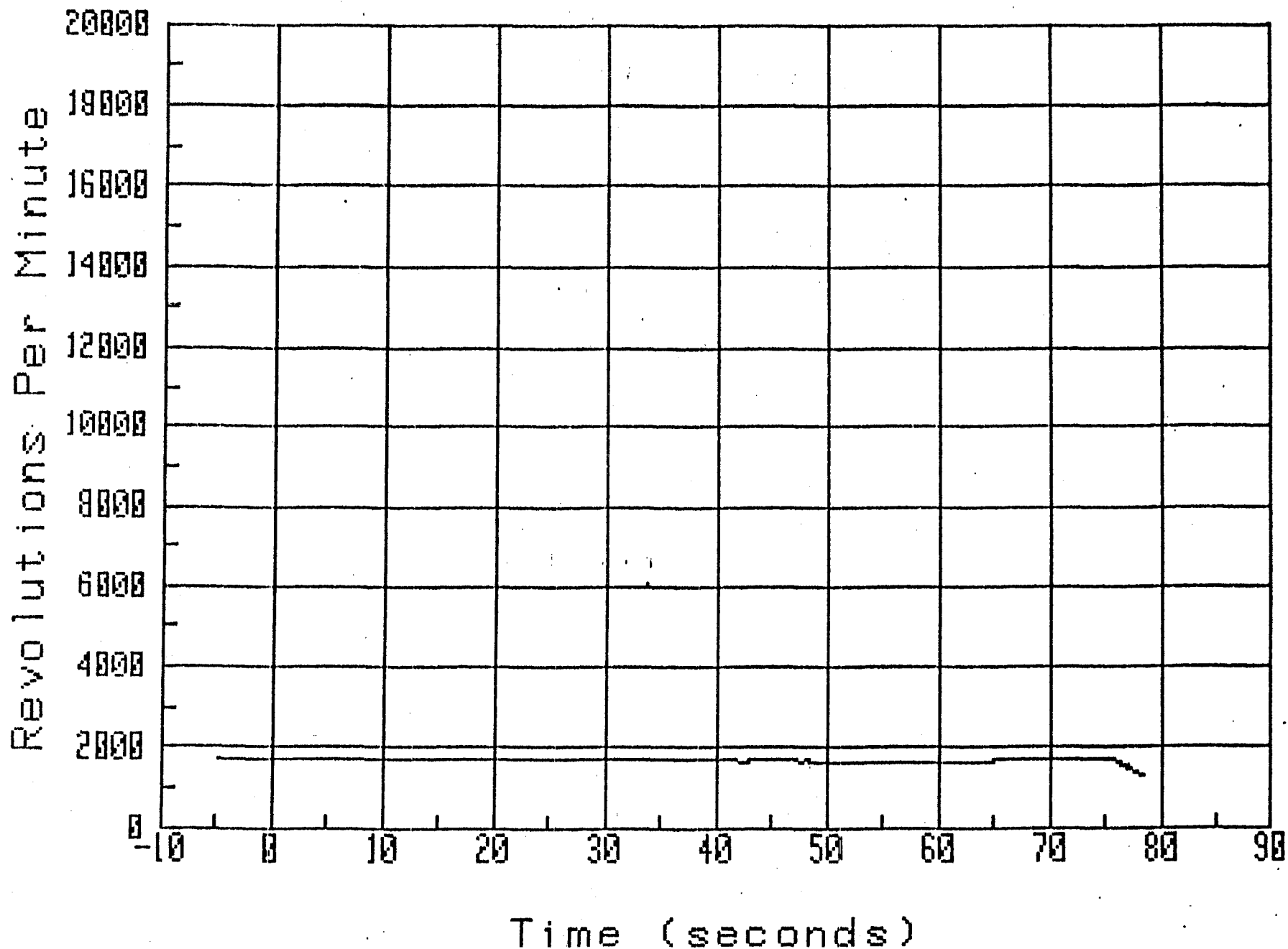
Constant torque load and a normal load offset.



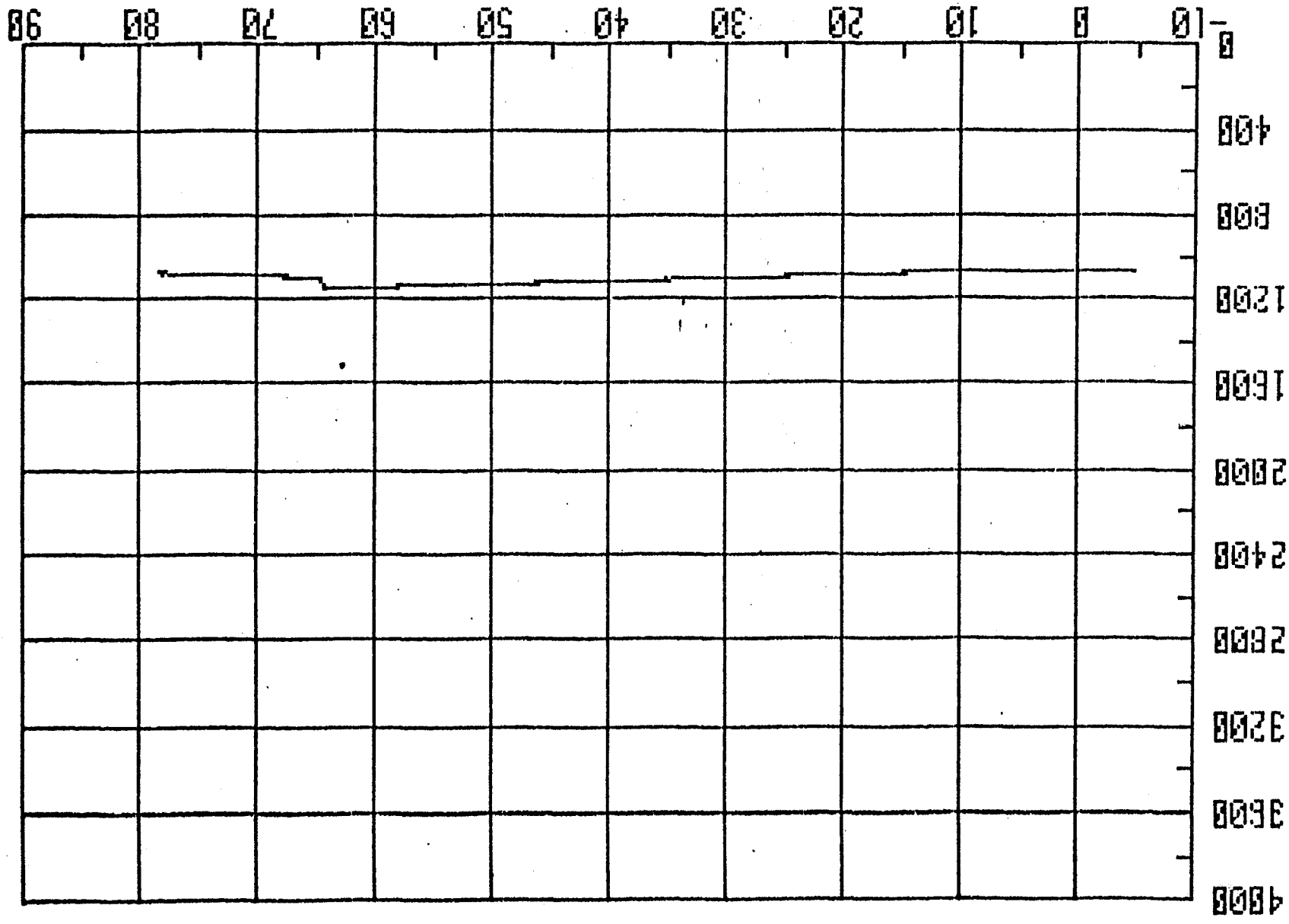
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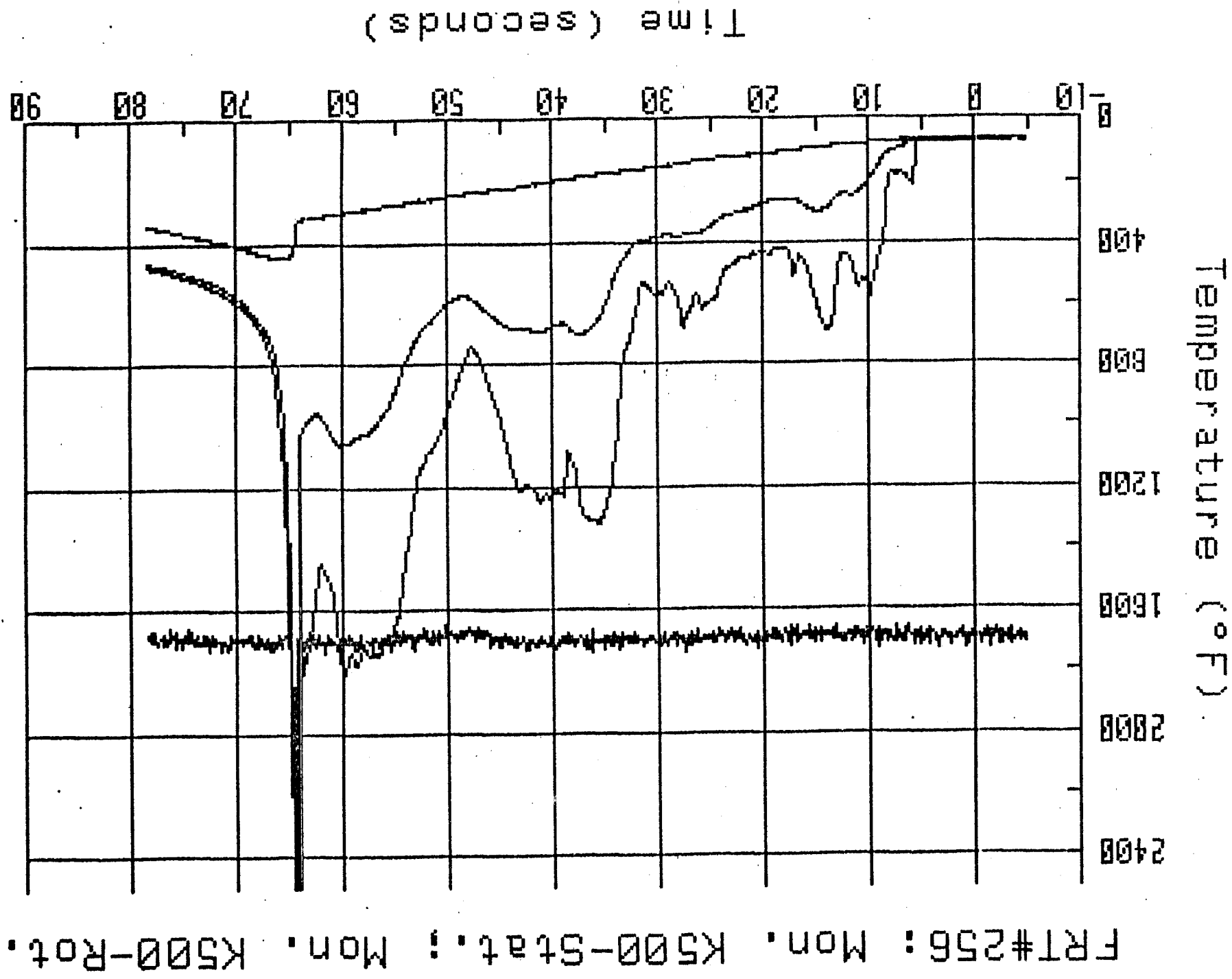
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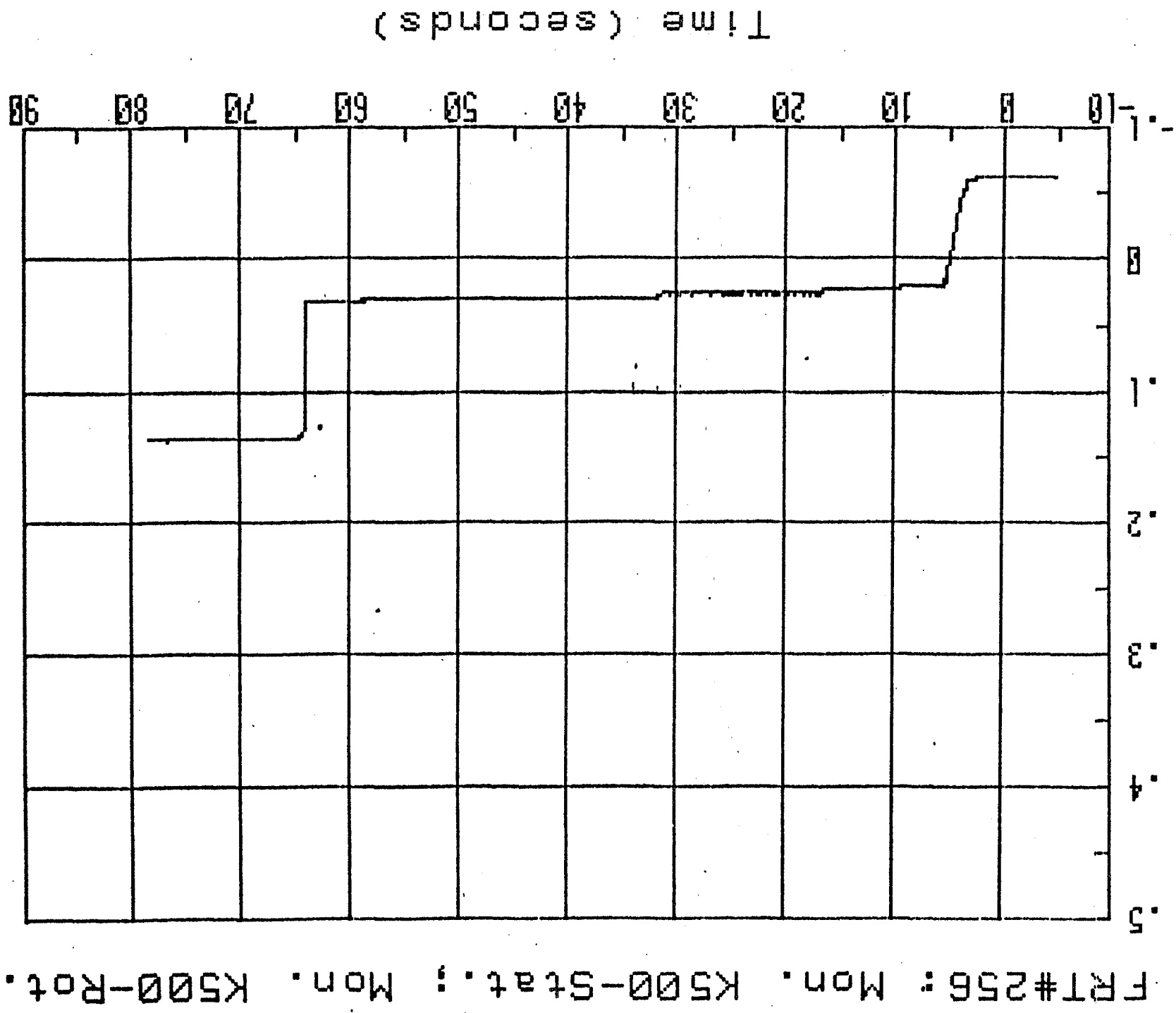
Chamber Oxygen Pressure (PSIG)



FRT#256: Mon. K500-Stat.; Mon. K500-Rot.



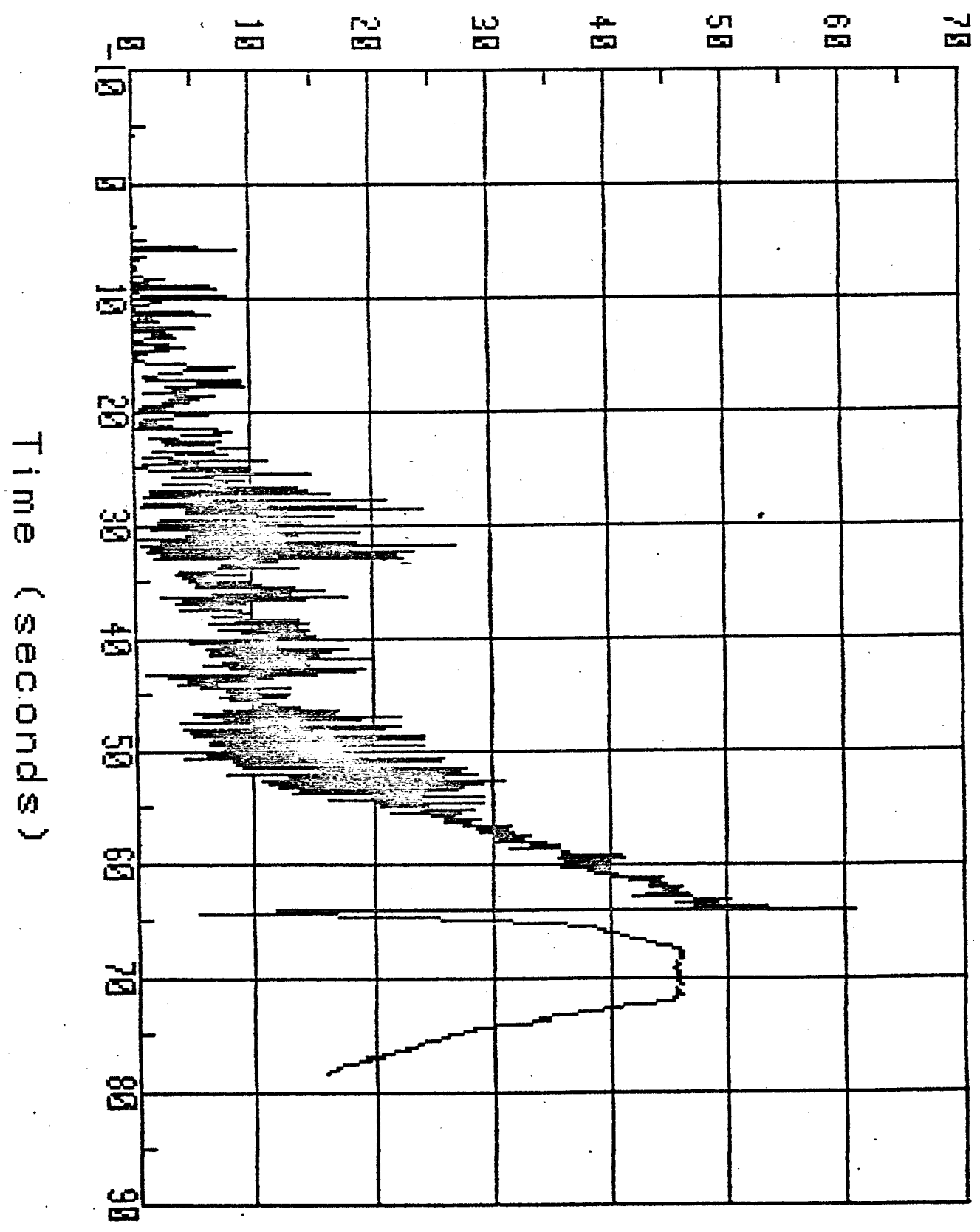
Sample Wear (Inches)



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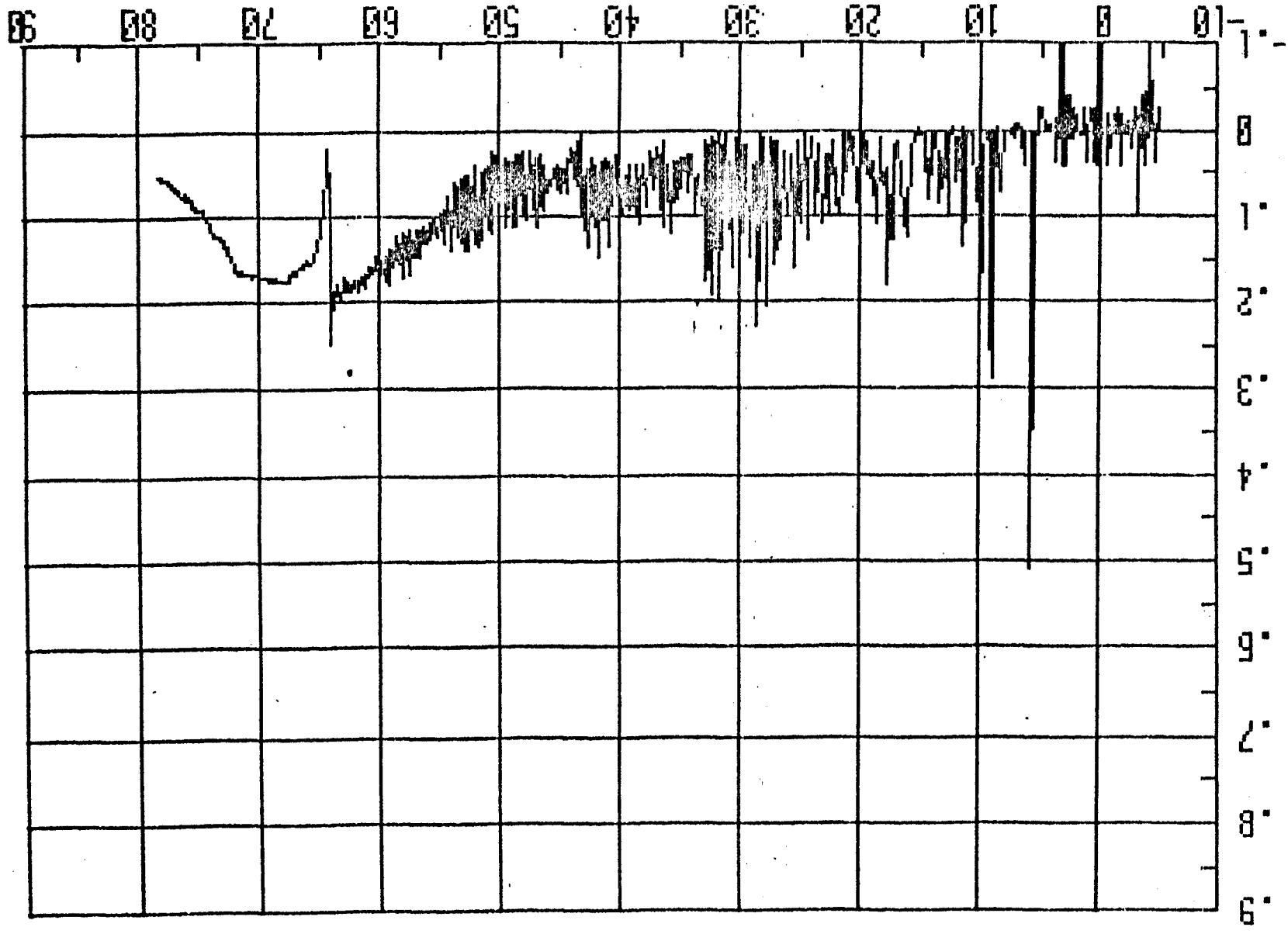
E-22

Torque Load (Lbf)



Contains a -2.6 load offset.

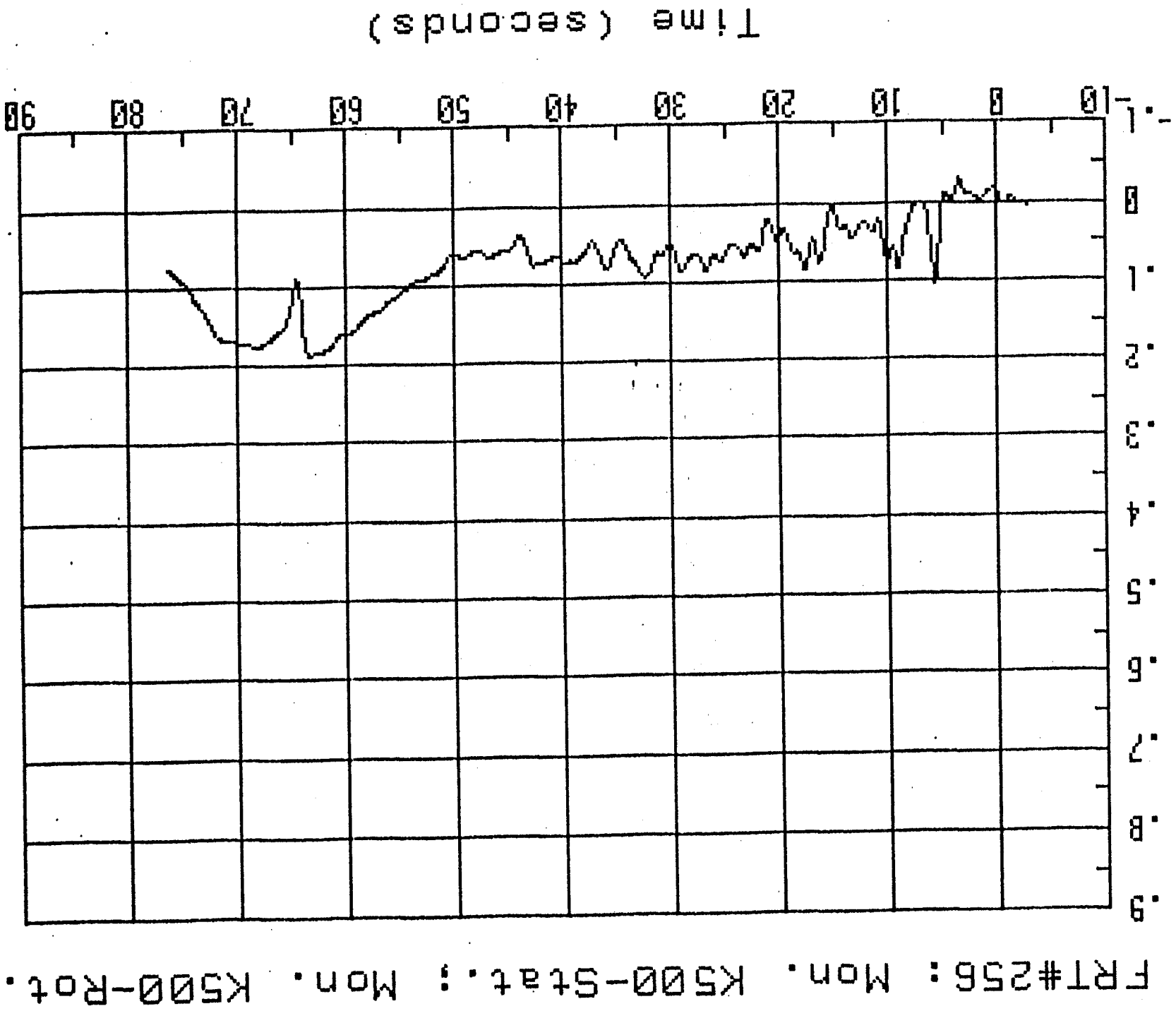
Coefficient of Friction



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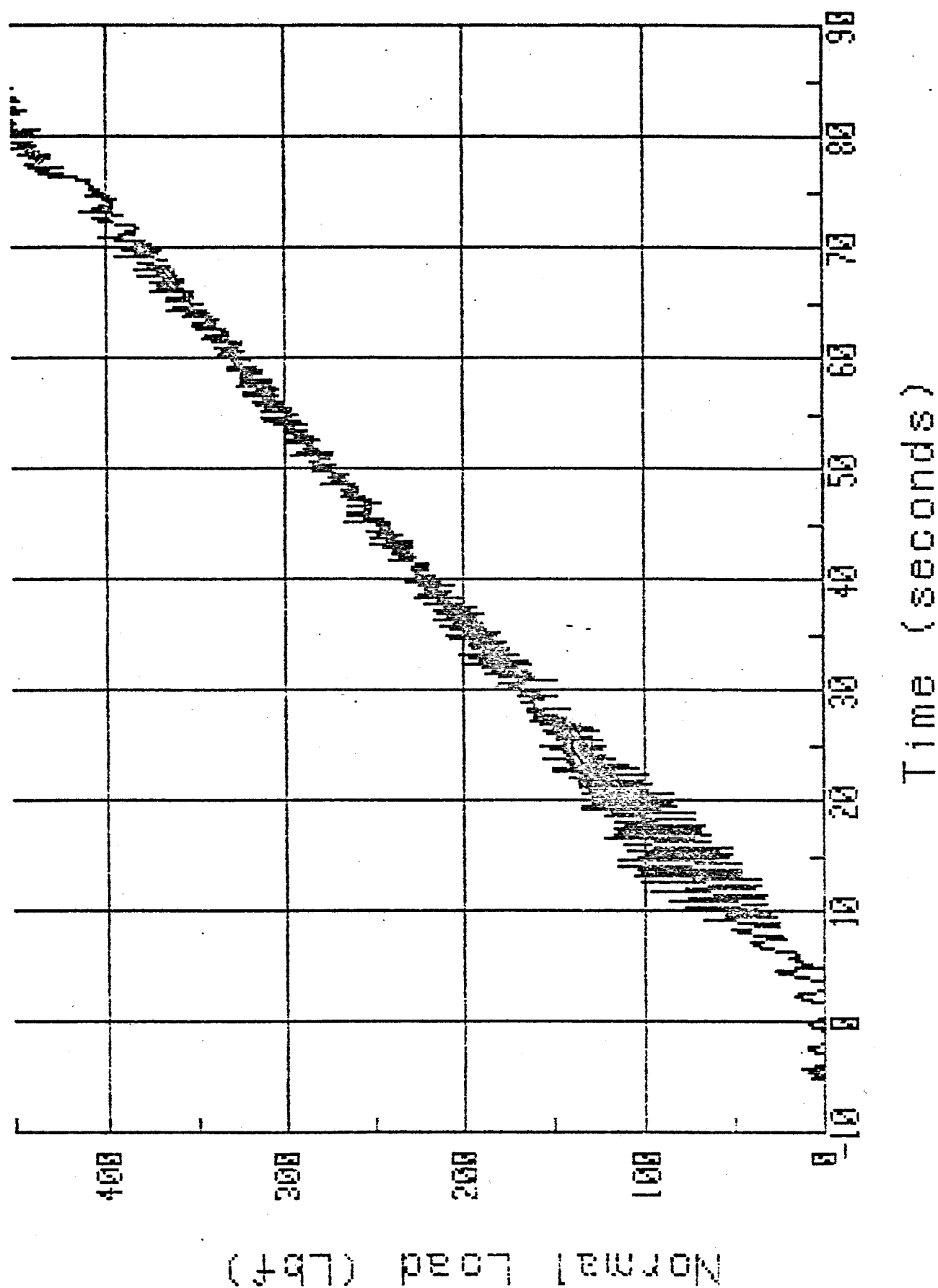
Combining a torque load and a normal load offset.

Filtered Coefficient of Friction

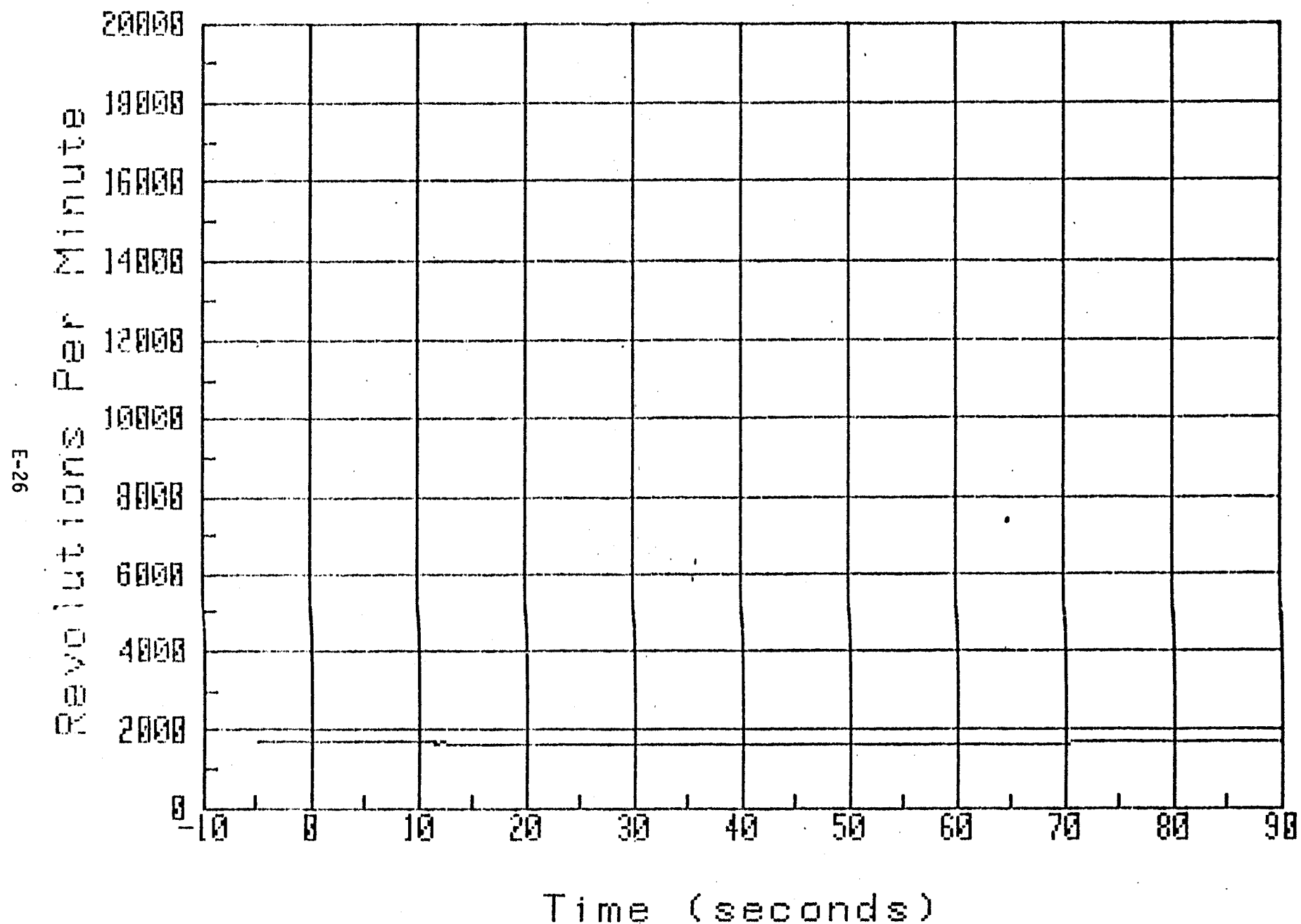


Positive a torque load and a normal load offset.

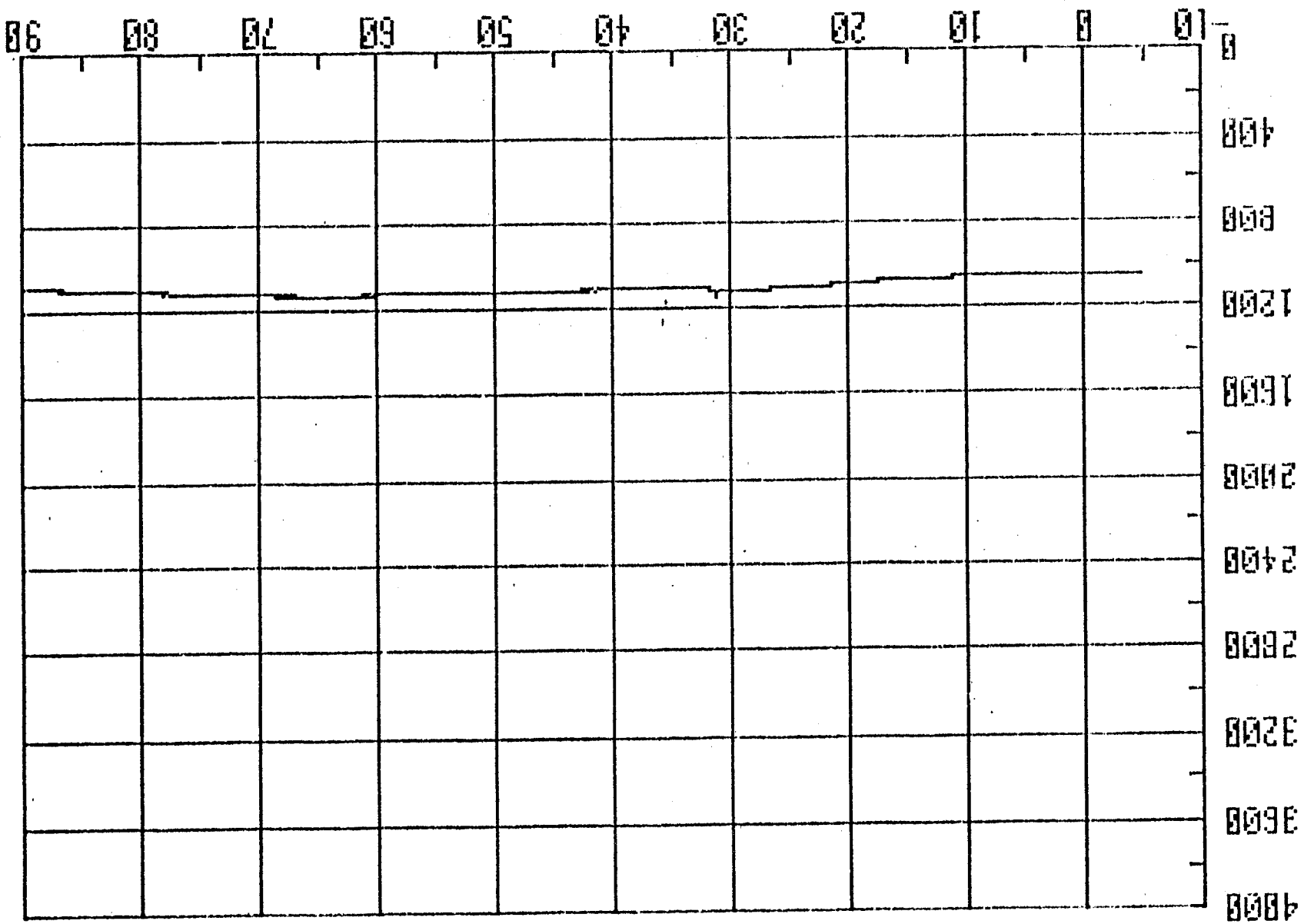
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FRT#257: ZrCu-Stat.; 316 SS-Rot.

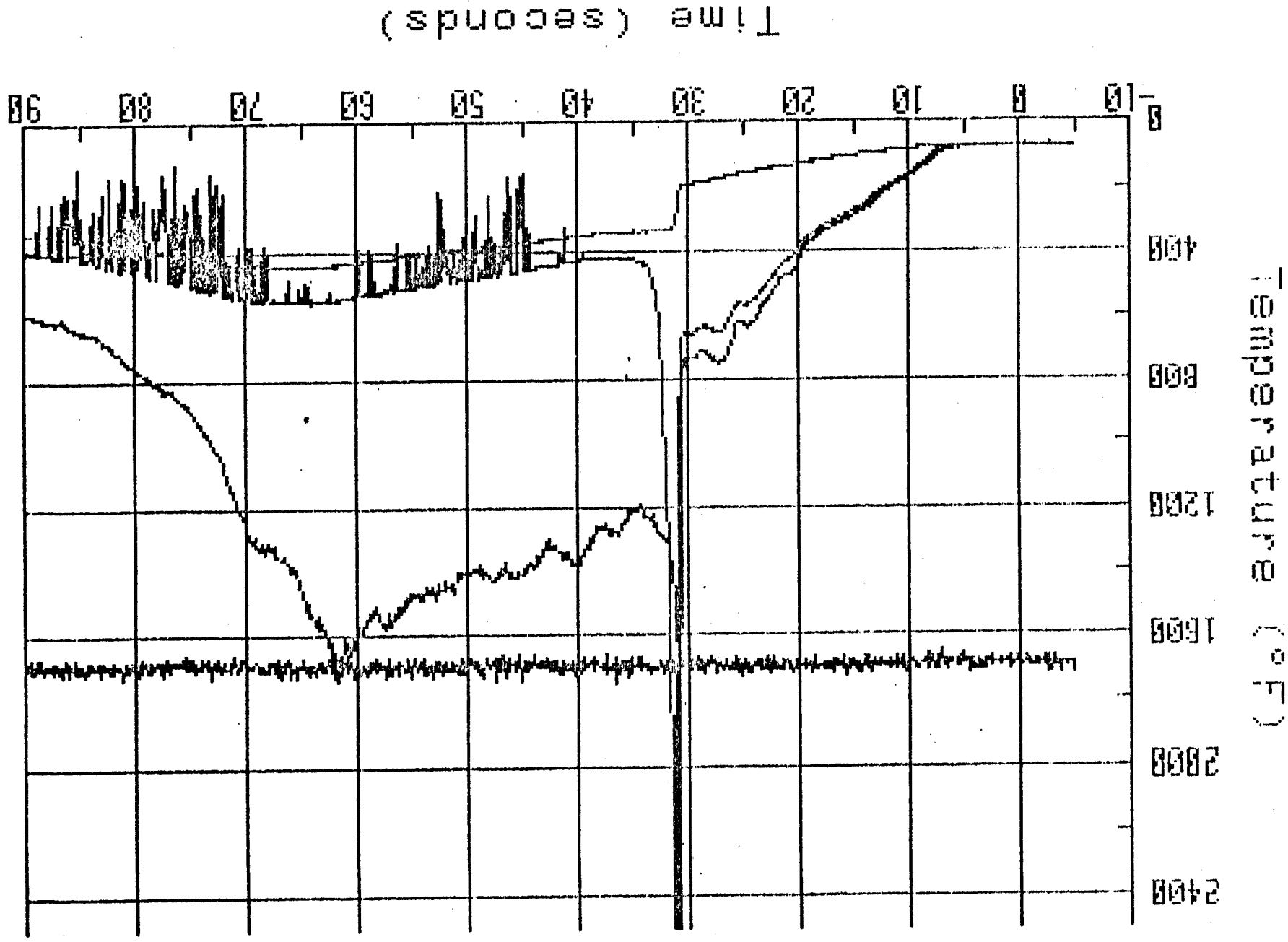


Chamber Oxygen Pressure (PSIG)

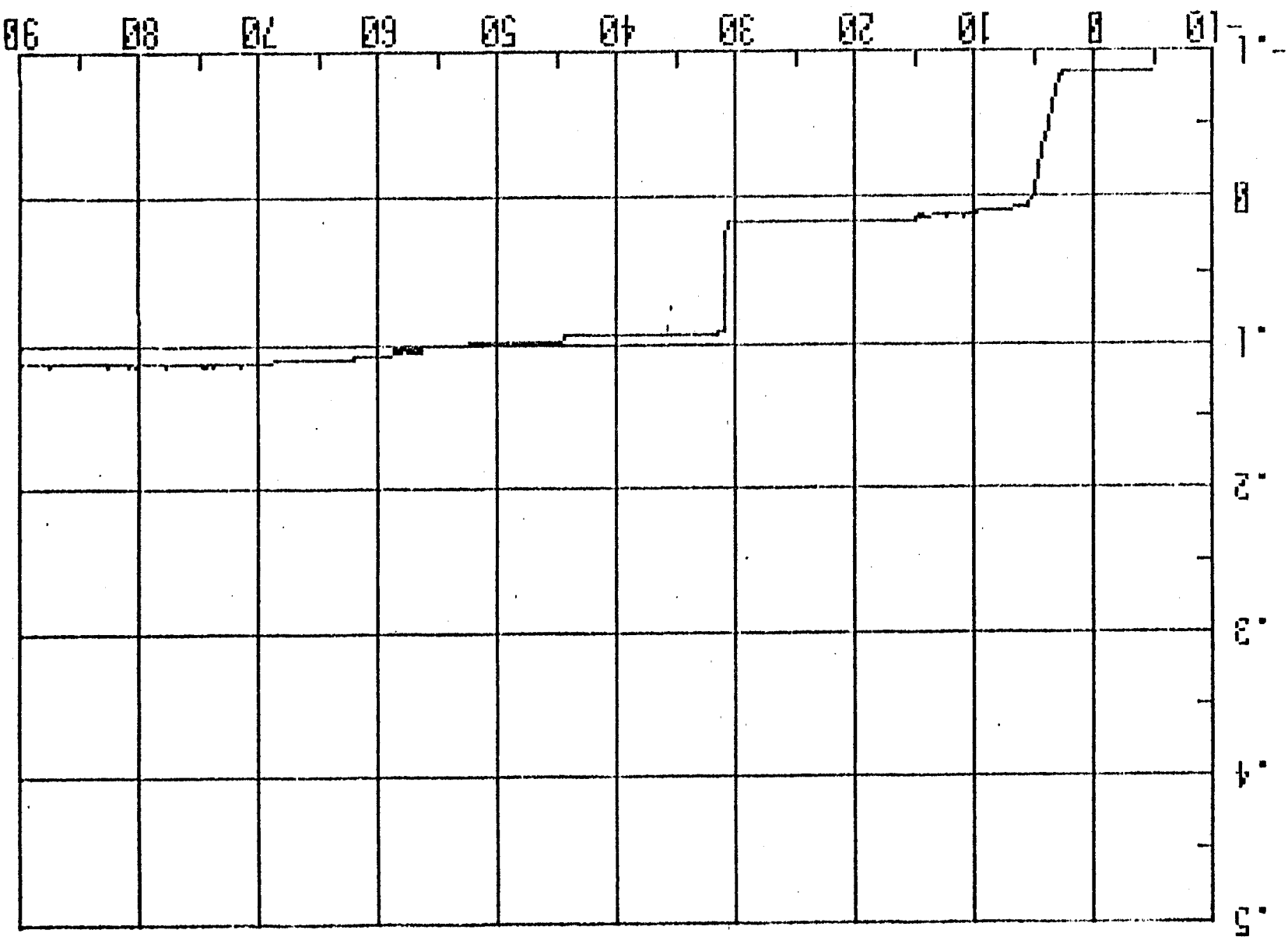


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FRT#257: ZrCu-Stat.; 316 SS-Rot.



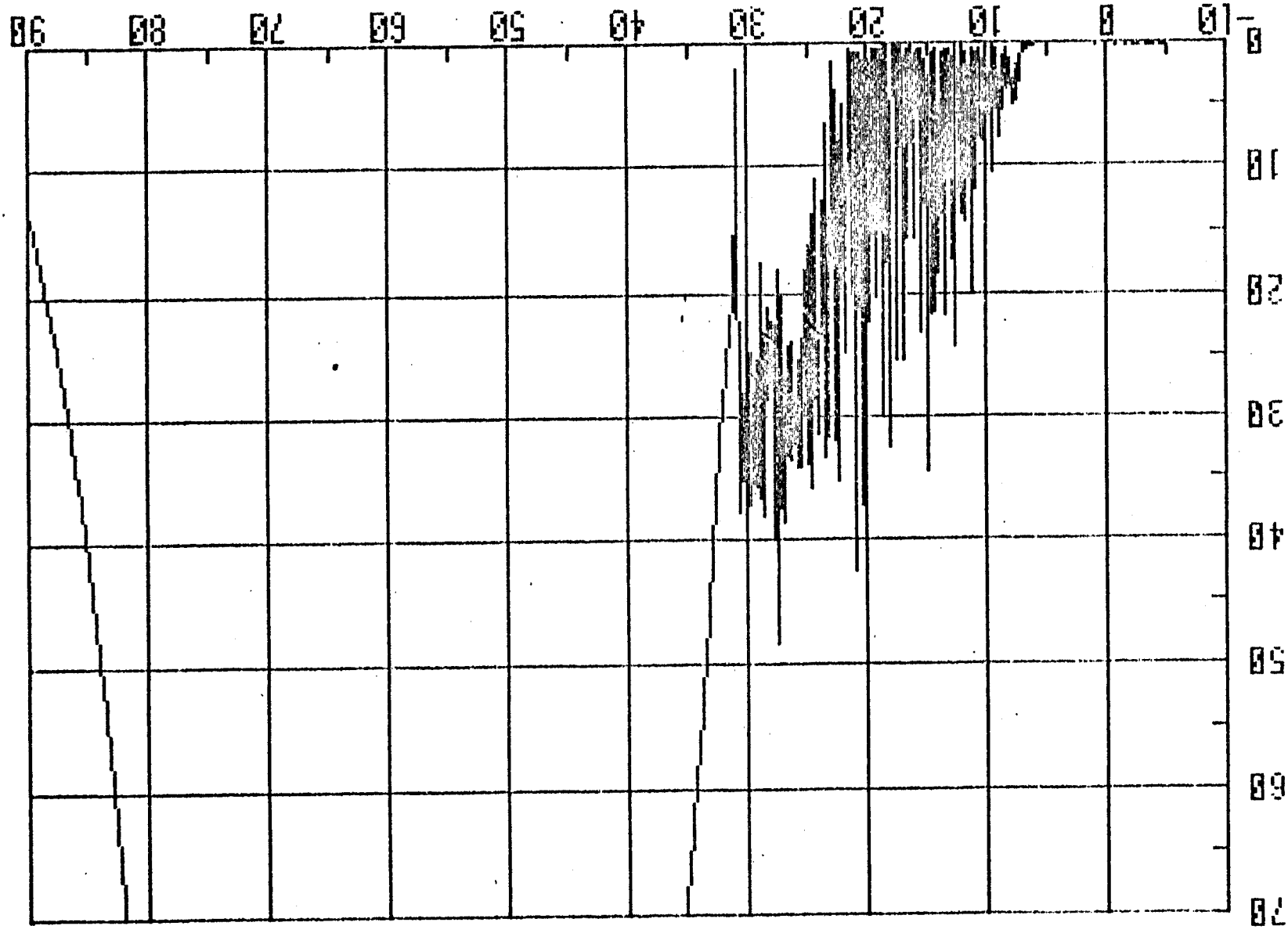
Sample Wear (Inches)



FRT#257: ZrCu-Stat.; 316 SS-Rot.

E-30

Torque Load (Lbf)

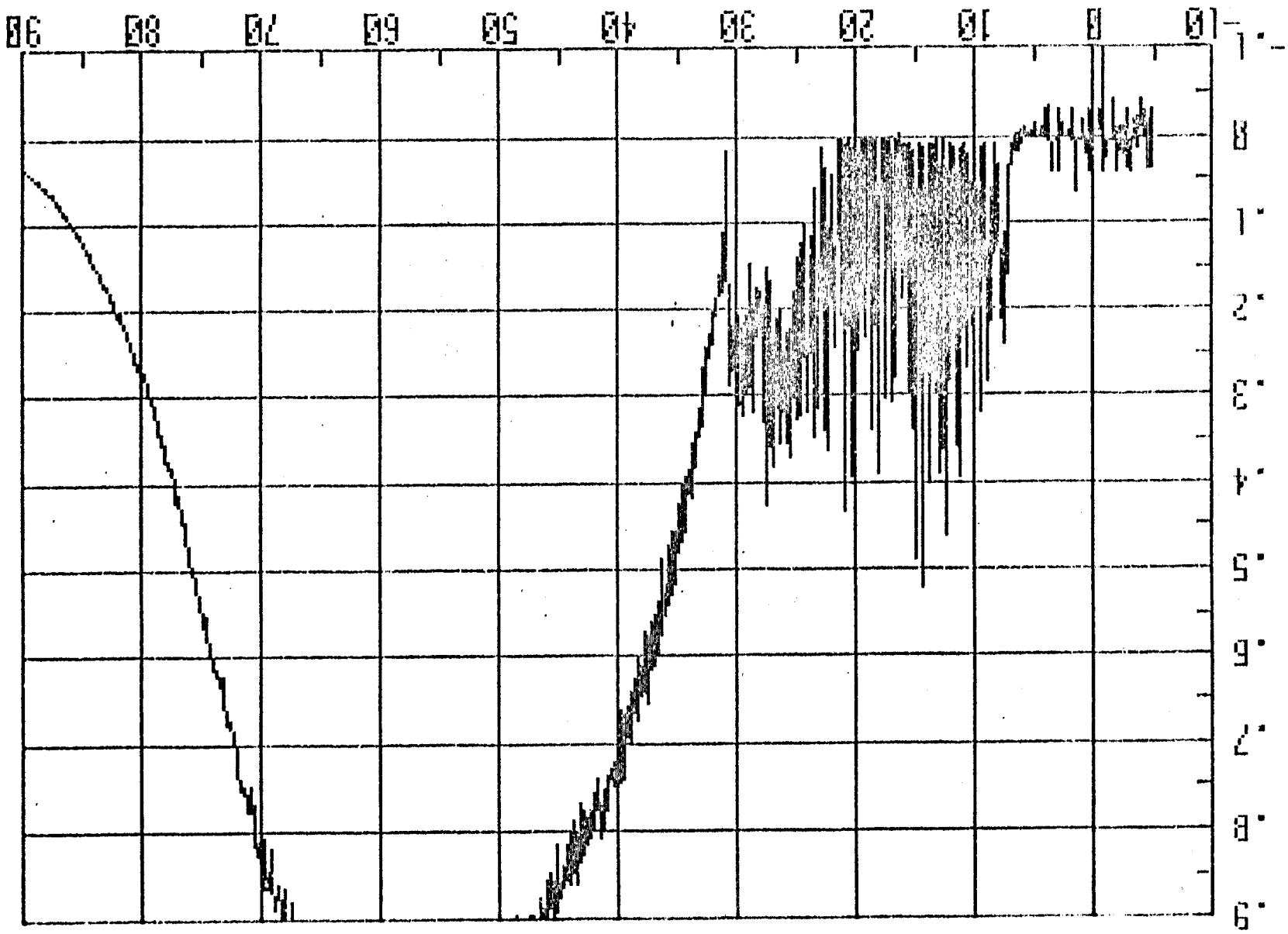


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Time (seconds)

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Coefficient of Friction



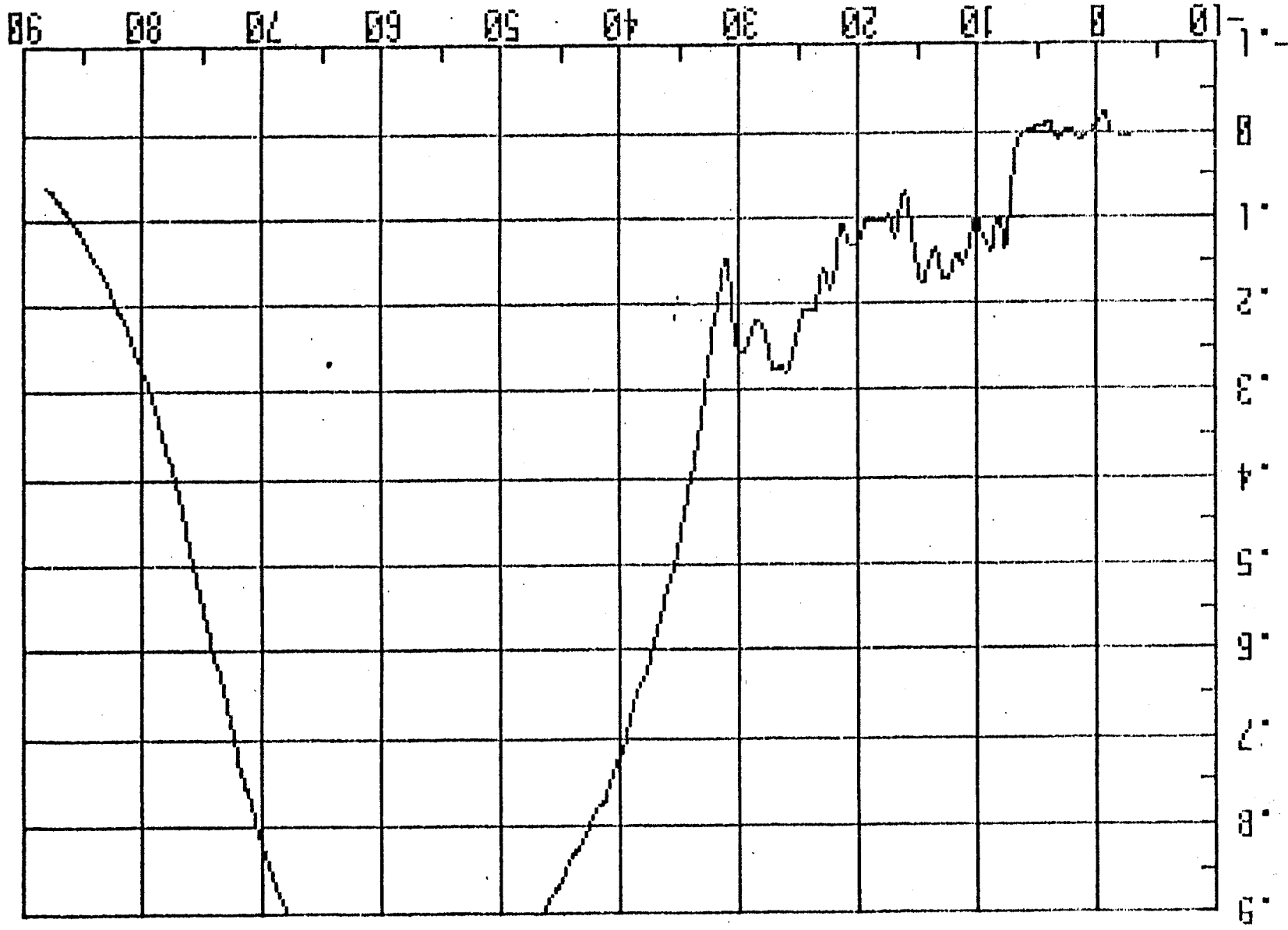
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Contains a torque load and a normal load offset.

Time (seconds)

E-32

Filtered Coefficient of Friction

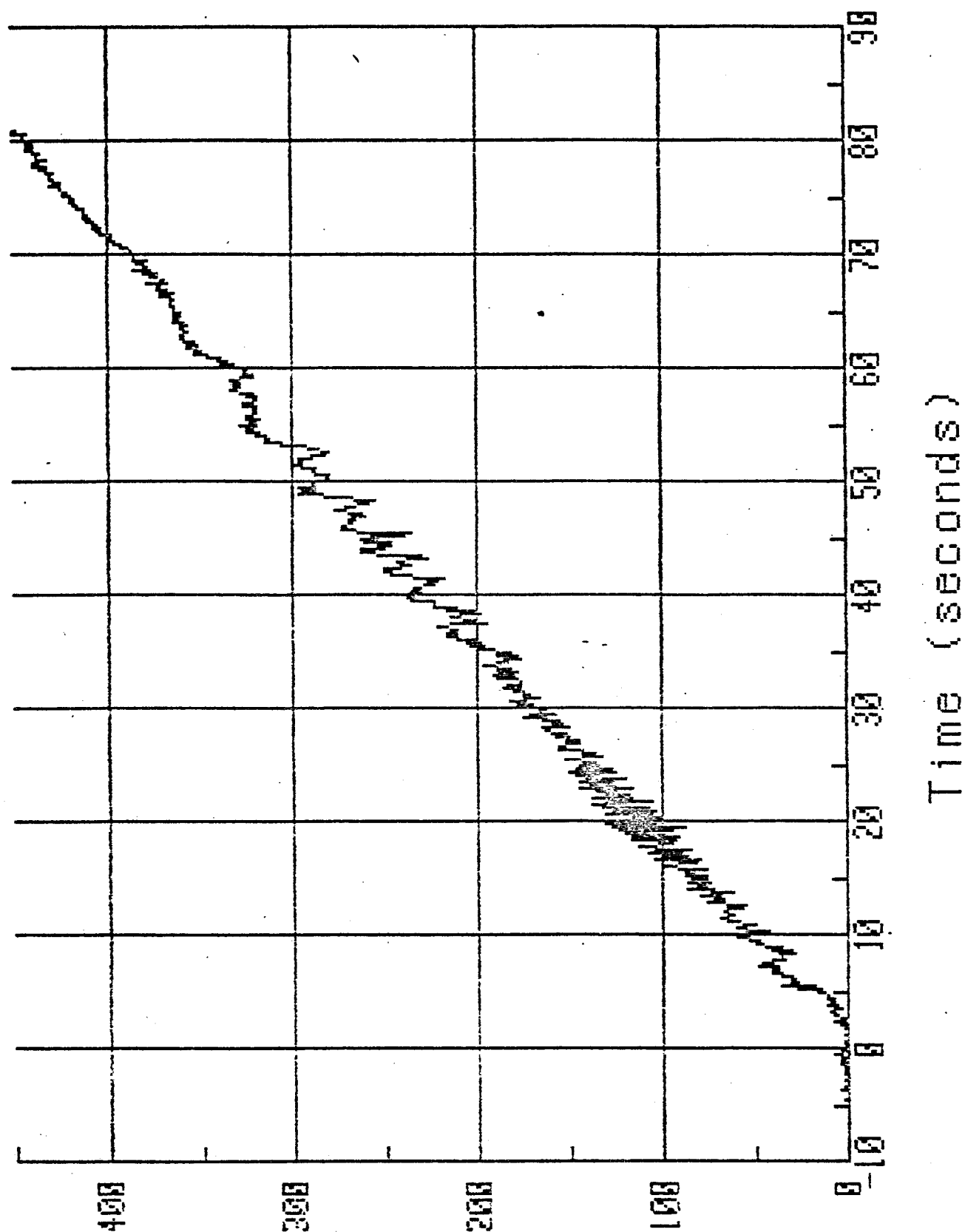


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Containing a torque load and a normal load offset.

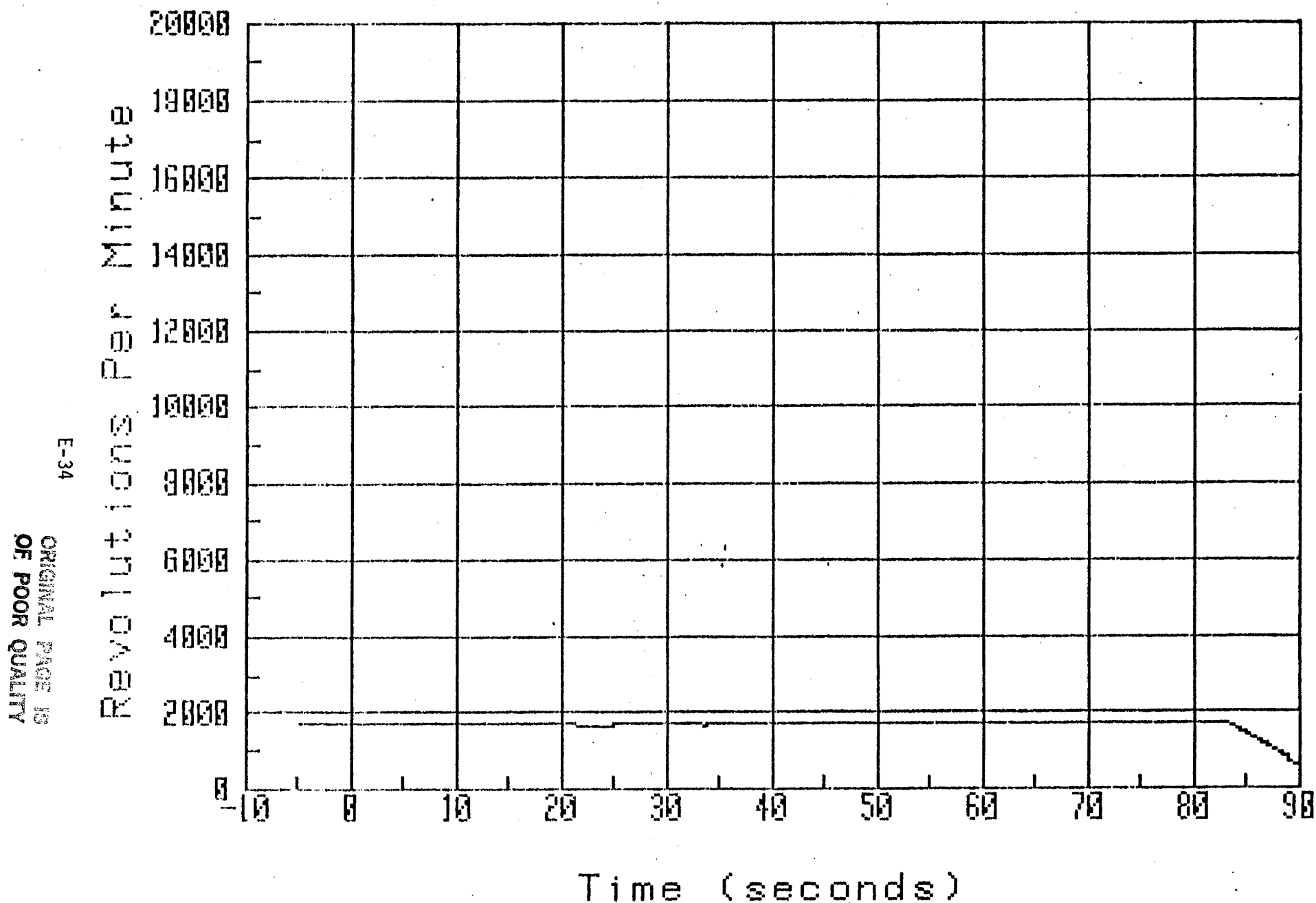
Time (seconds)

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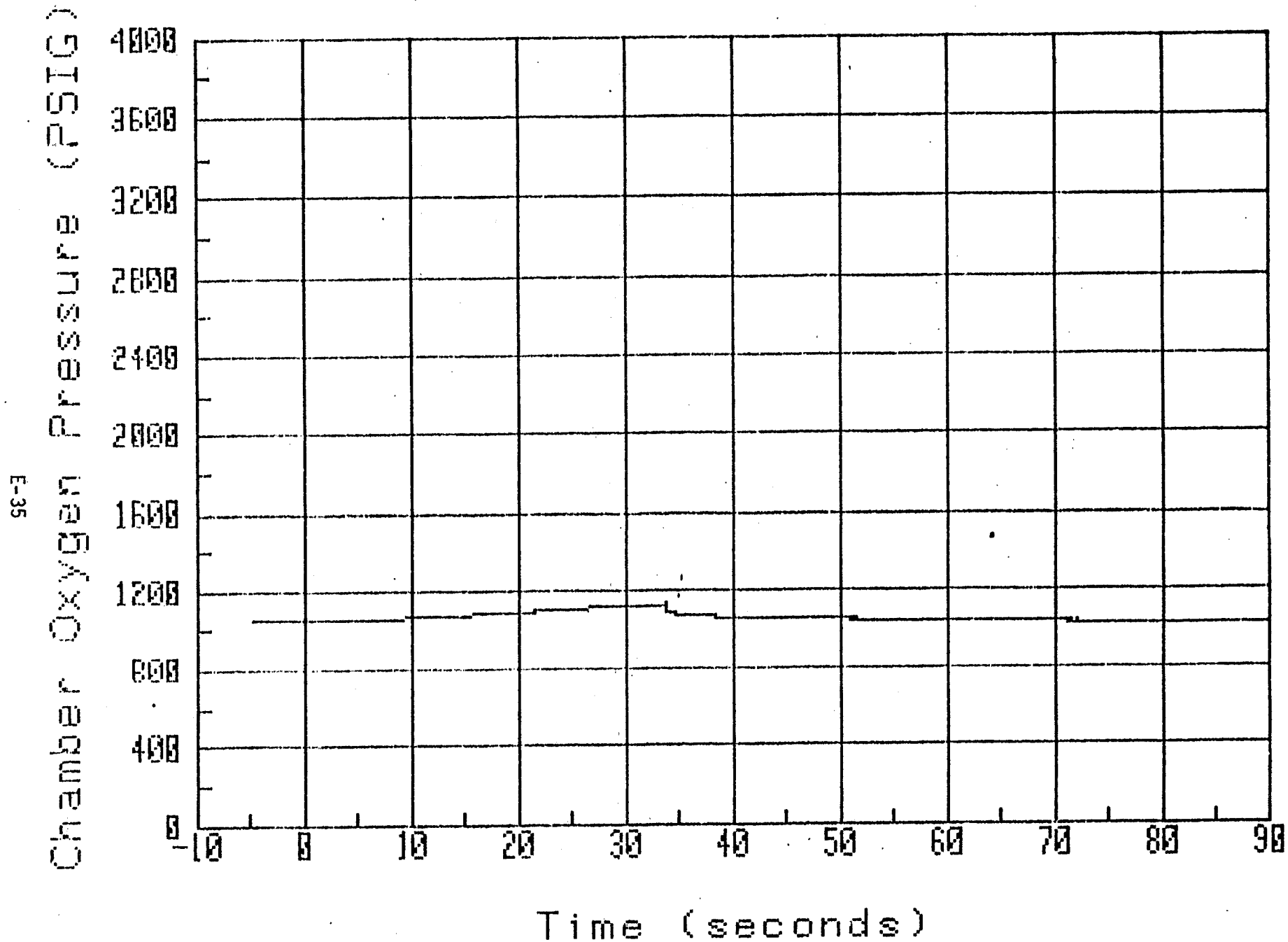


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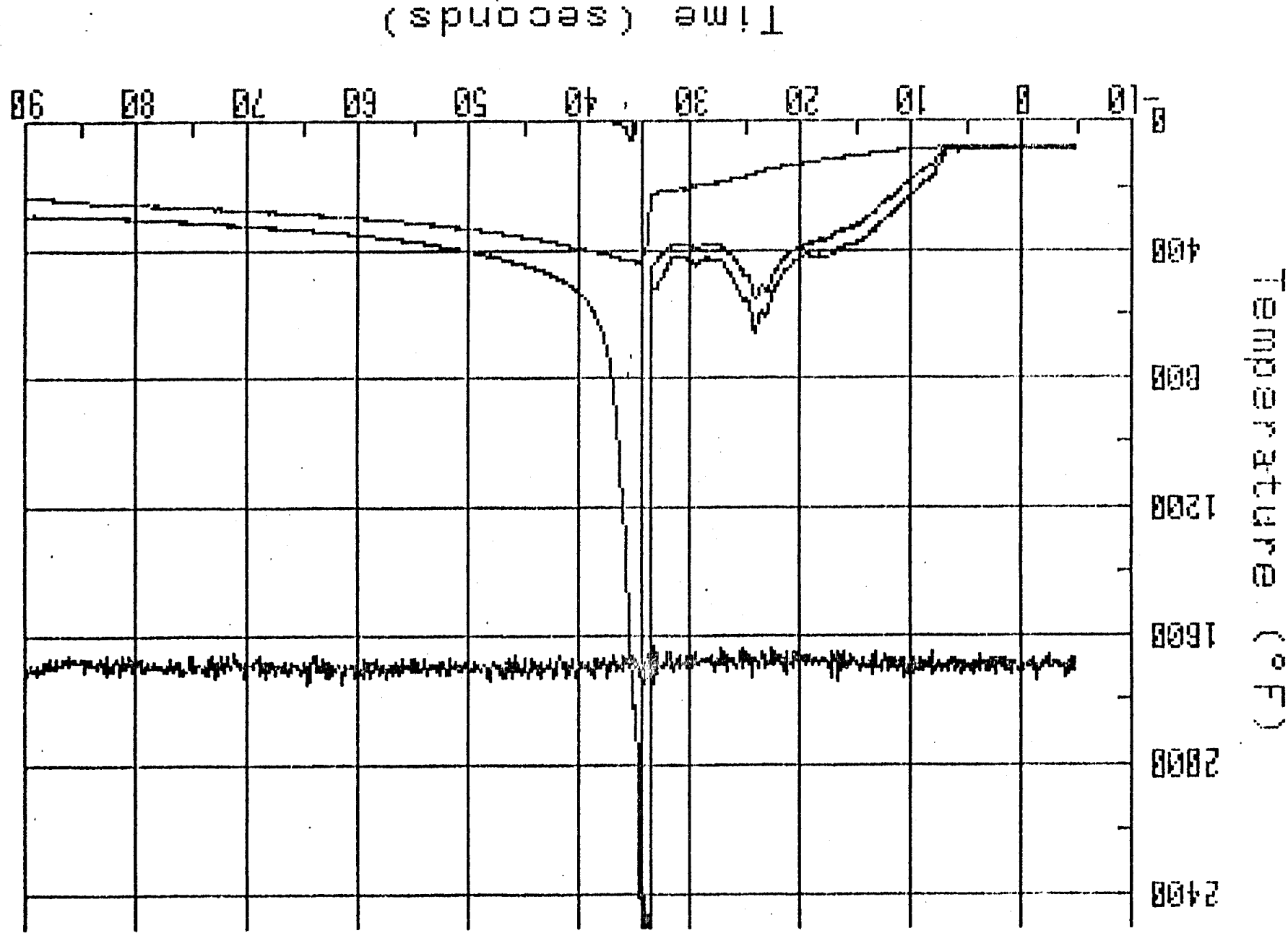
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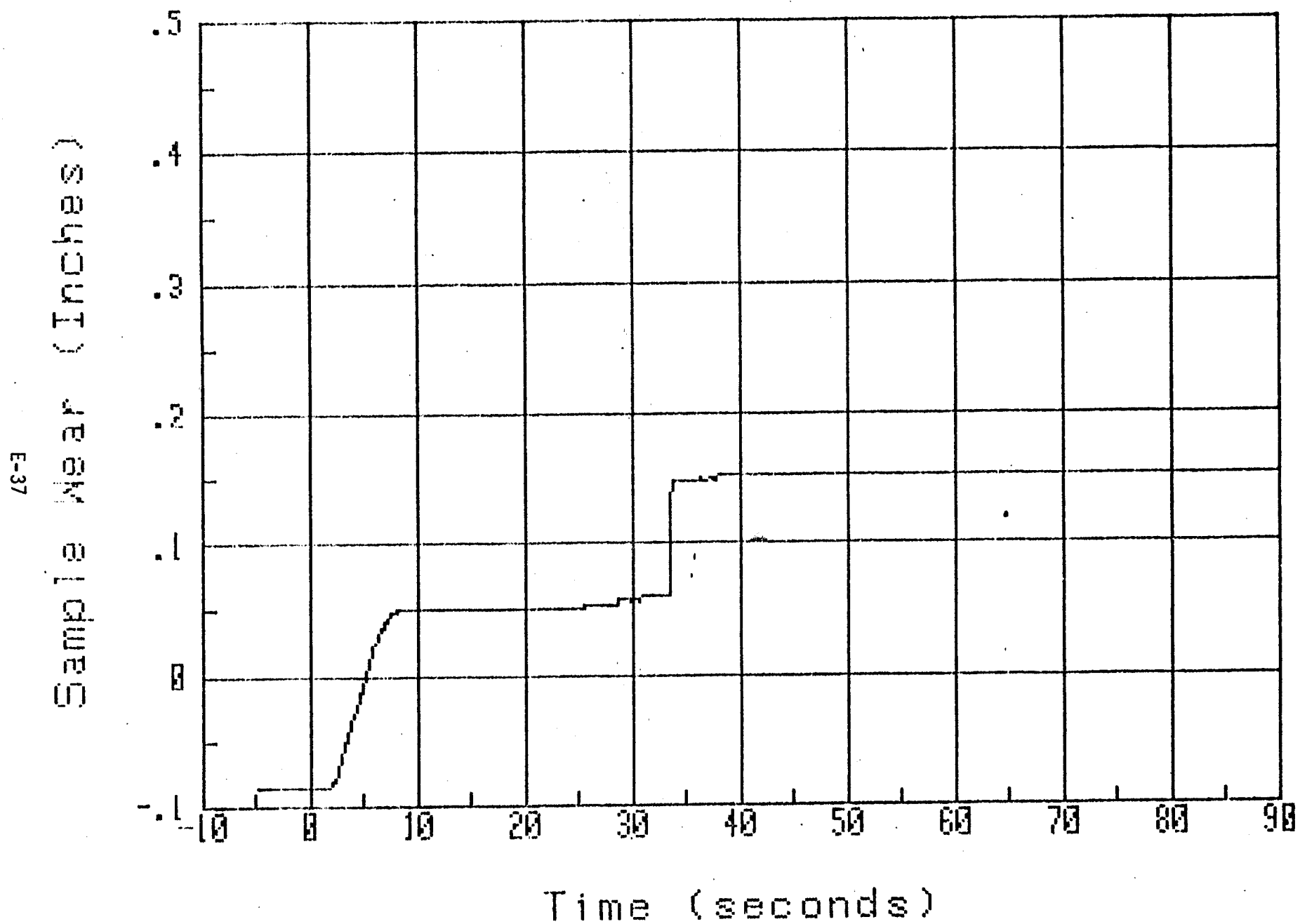
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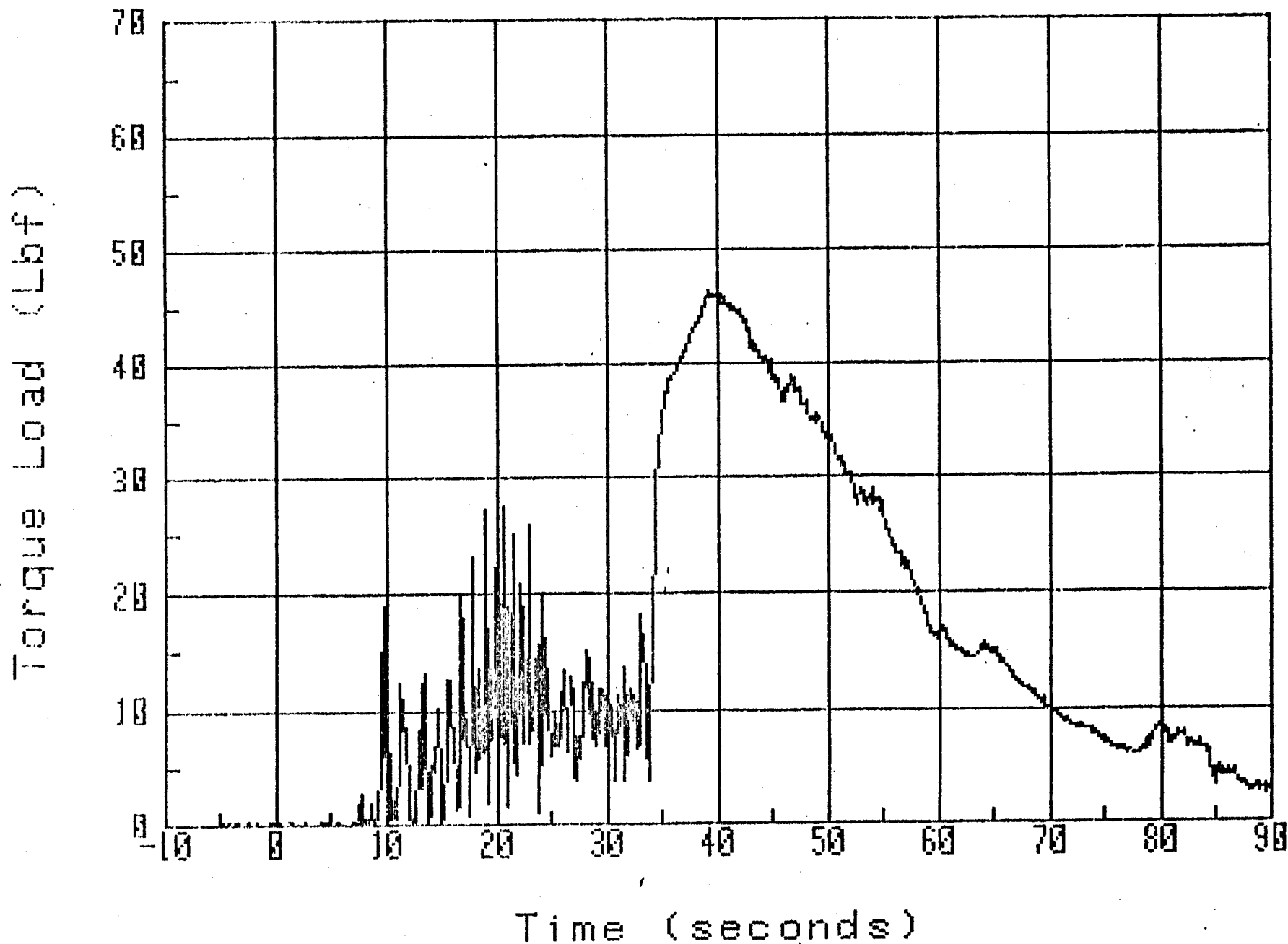
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FRT#258: ZrCu-Stat.; 316 SS-Rot.



FRT#258: ZrCu-Stat.; 316 SS-Rot.

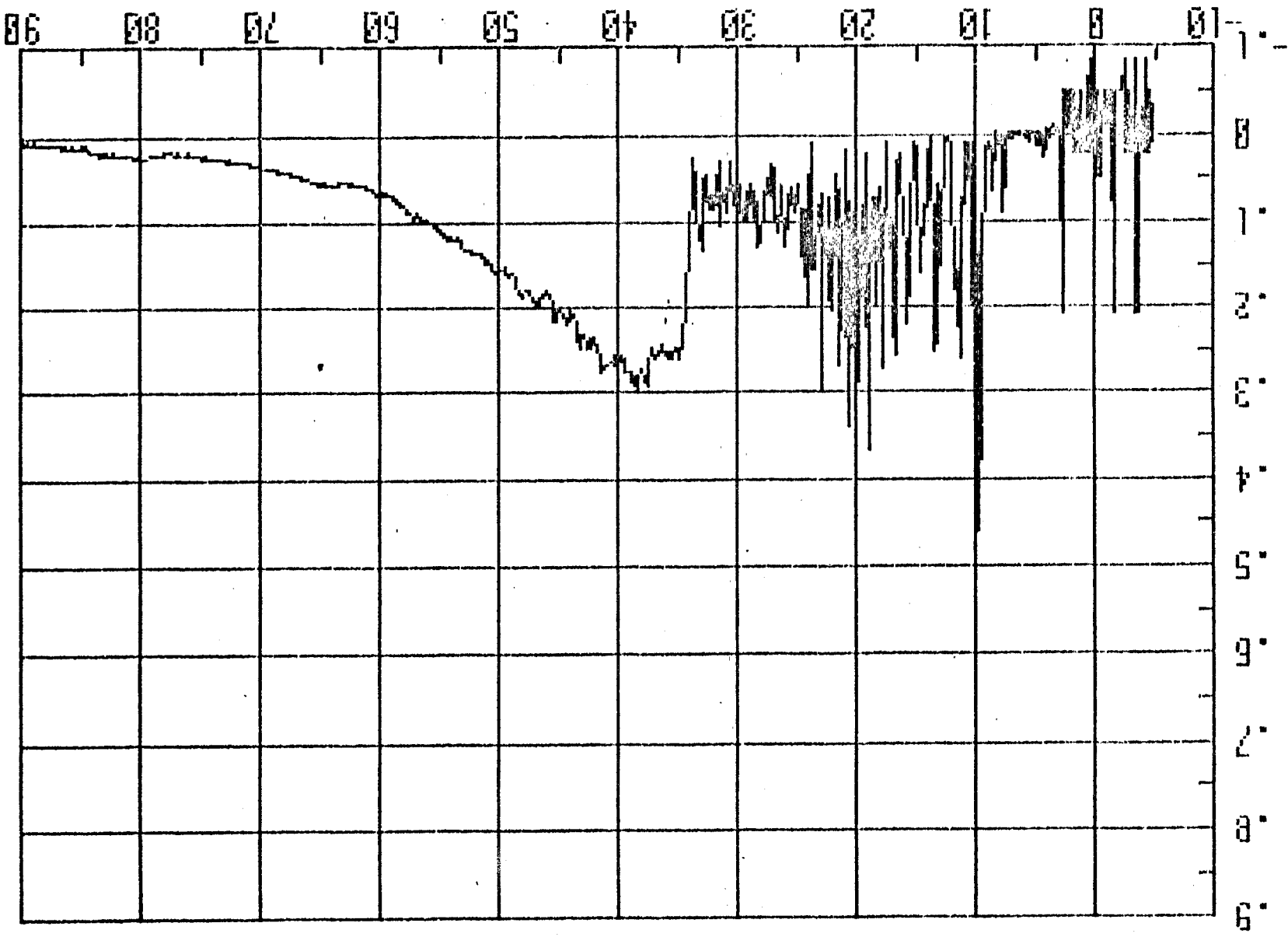


Contains a -3.4 load offset.

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Coefficient of Friction

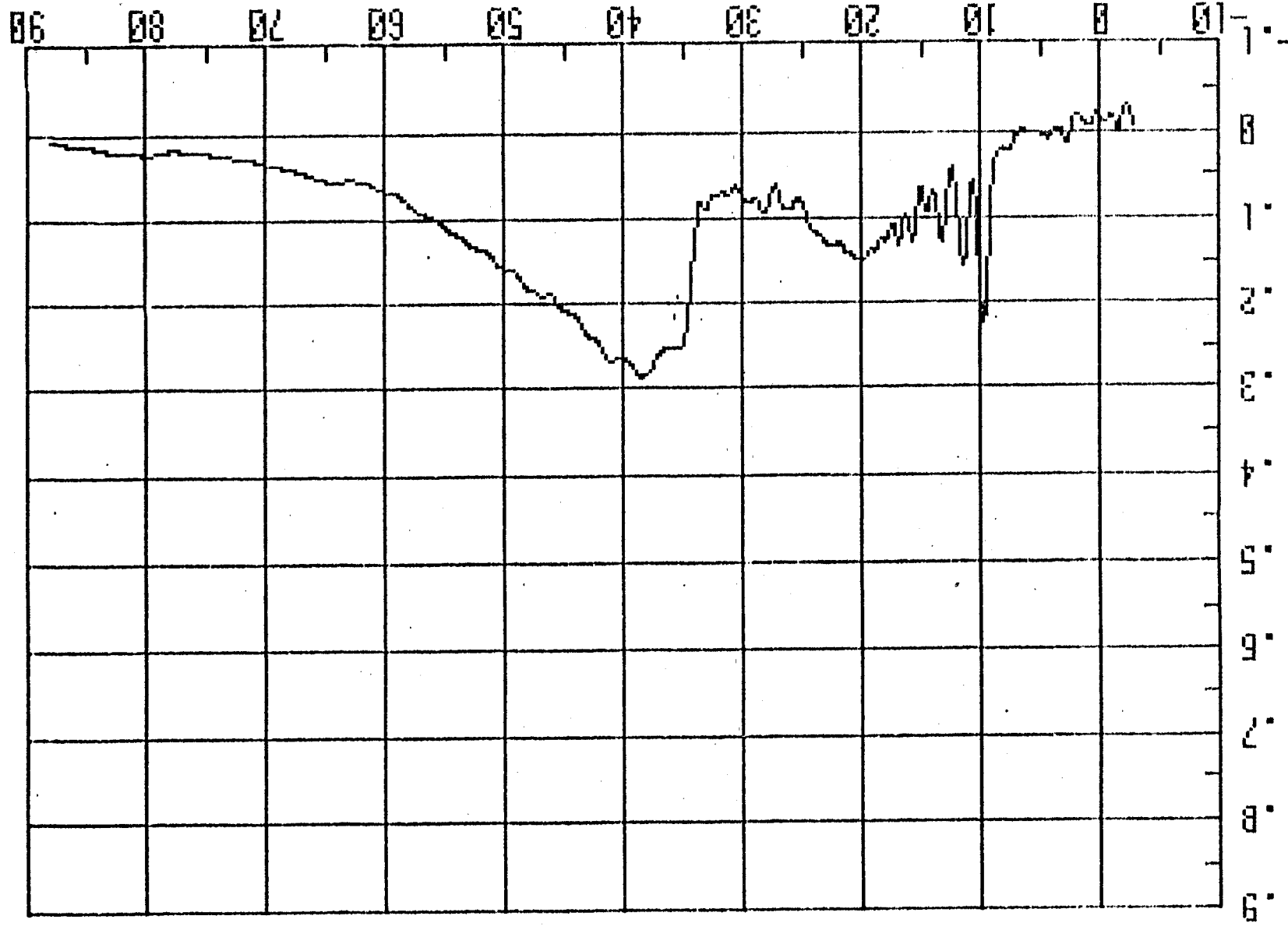
E-39



ALWAYS ROT. IN
IN HARD TISSUE

Time (seconds)
Contains a torque load and a normal load offset.

FRT#258: ZrCu-Stat.; 316 SS-Rot.



Time (seconds)

Containing a torque load and a normal load offset.

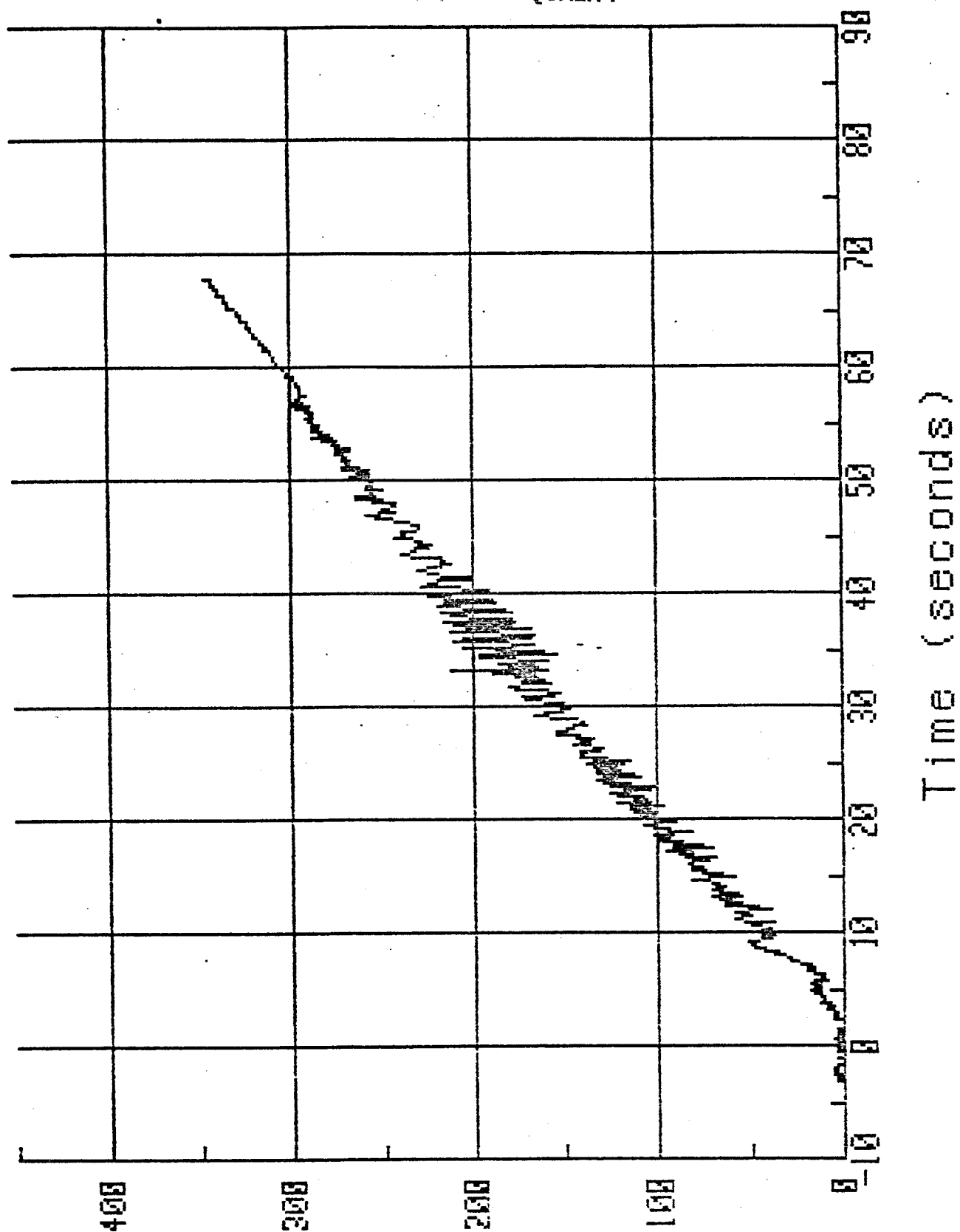
NOI12014740 of Friction Coefficient

E-40

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OF POOR QUALITY

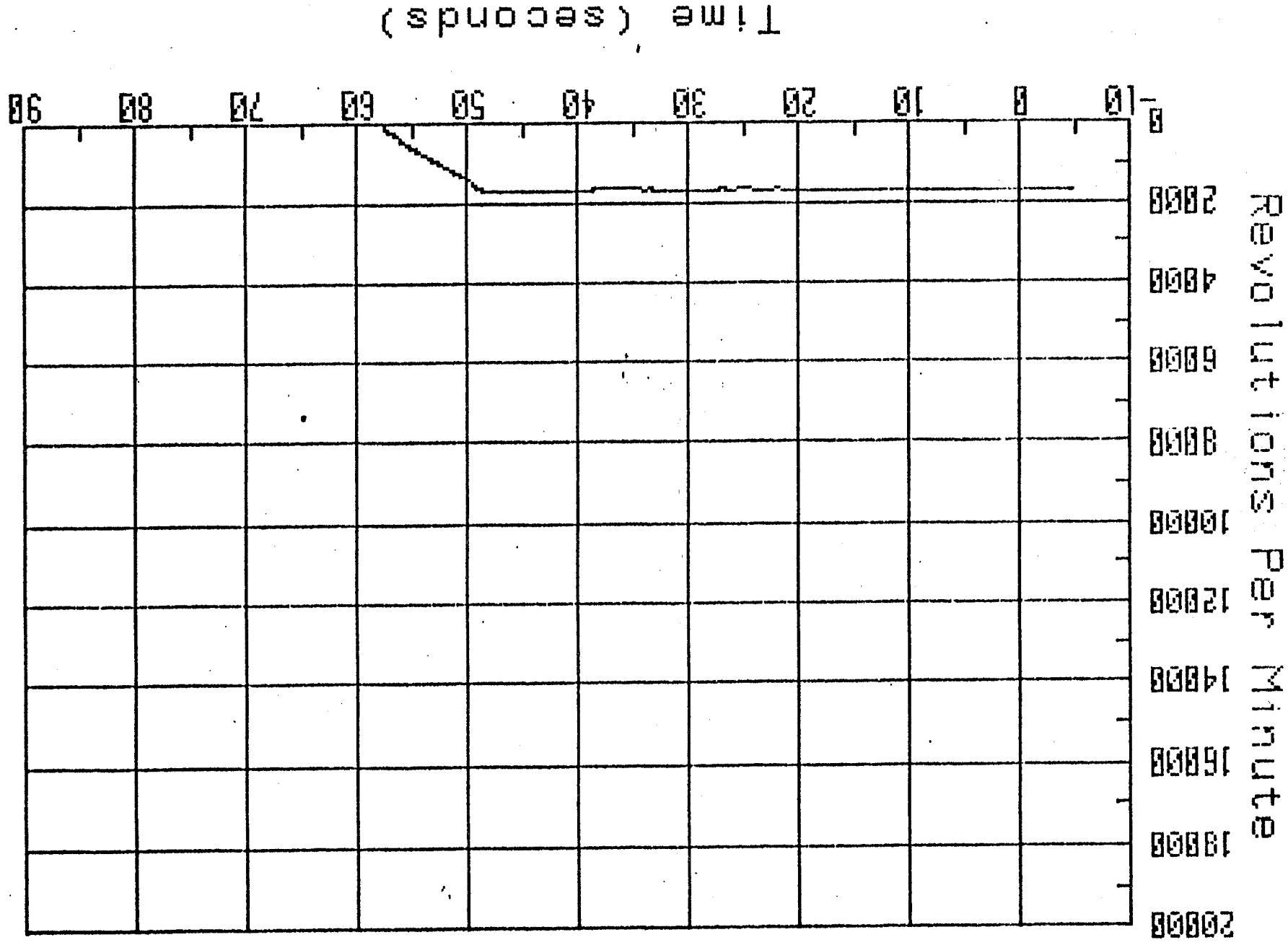
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(+97) 0207 12000N

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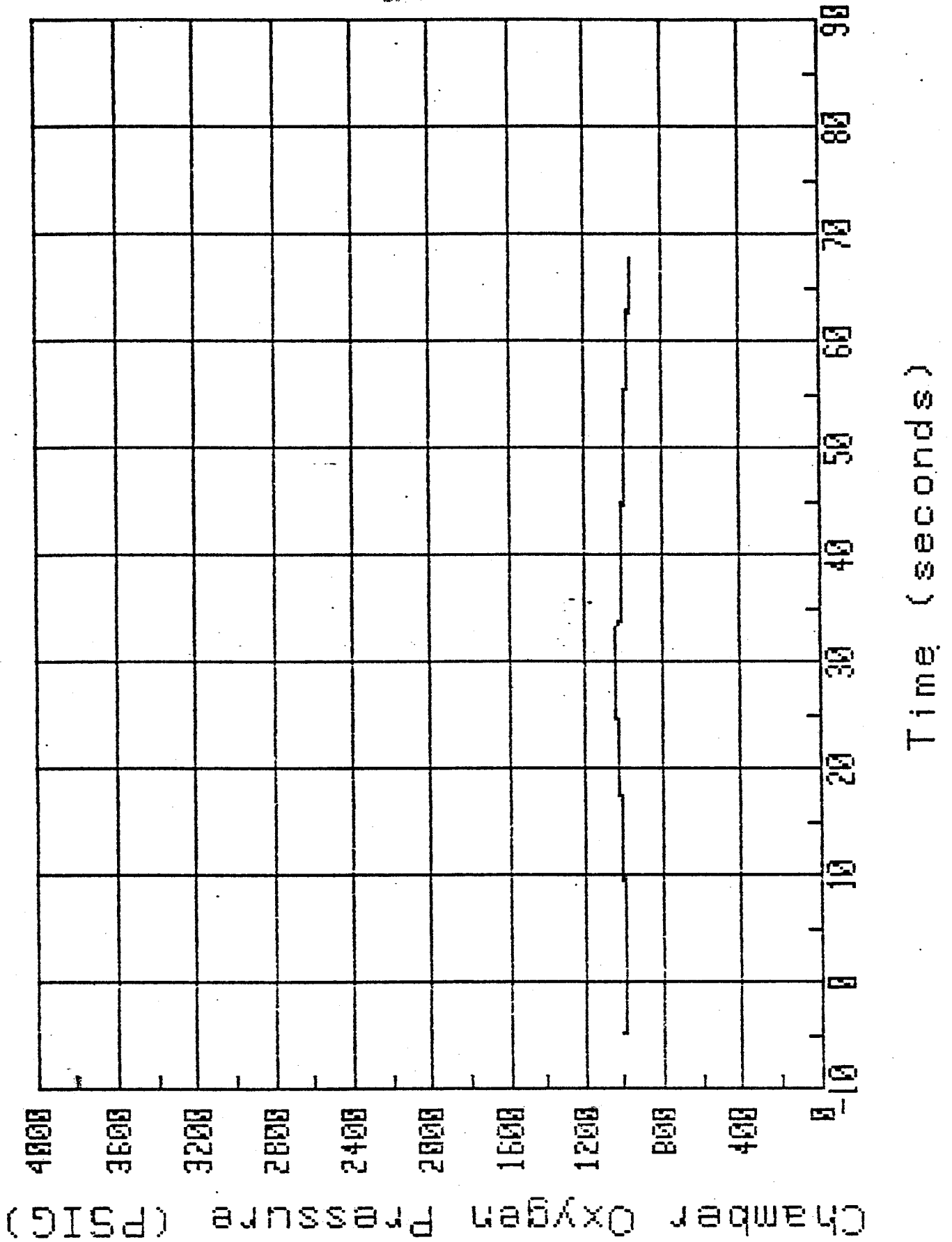


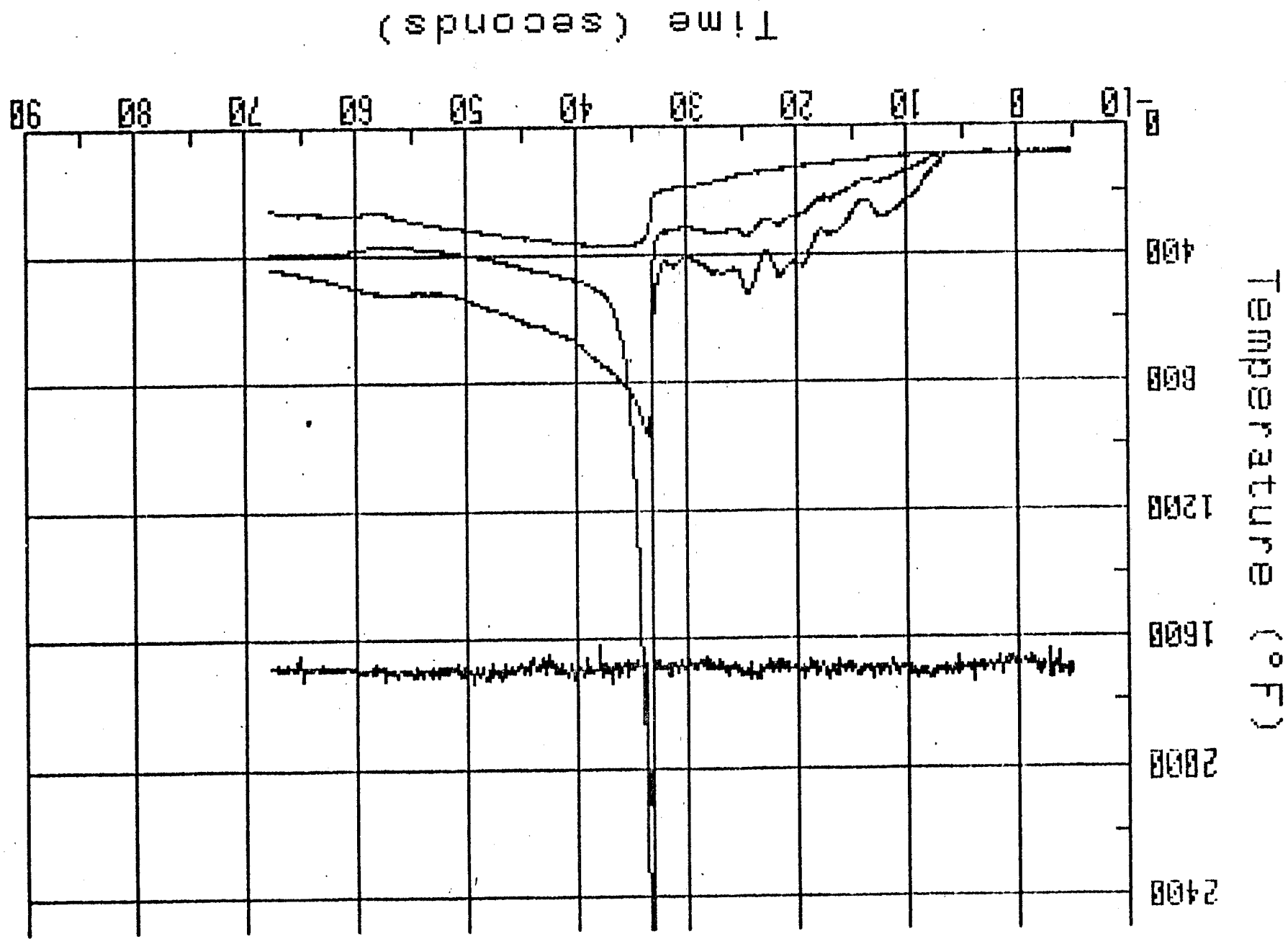
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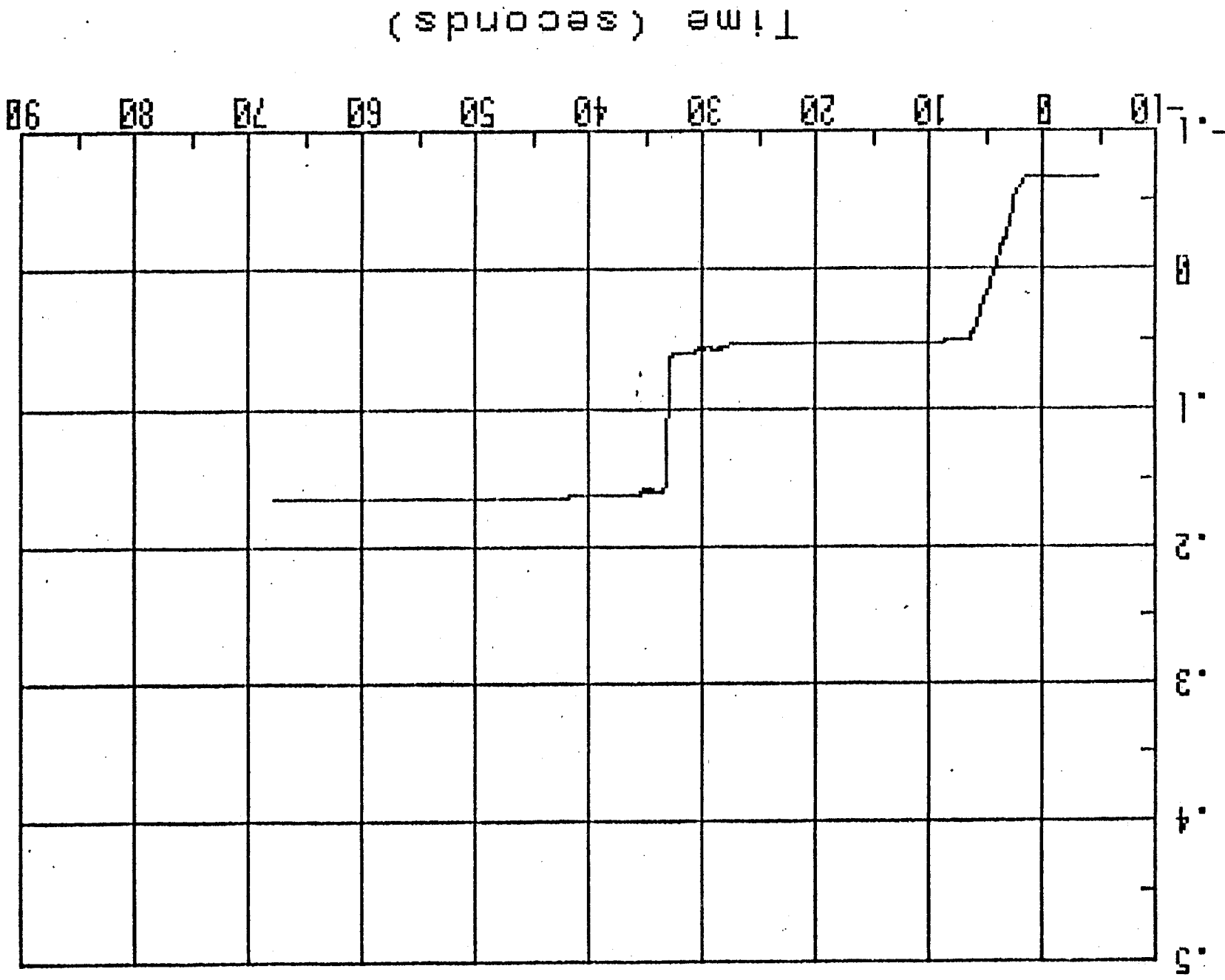
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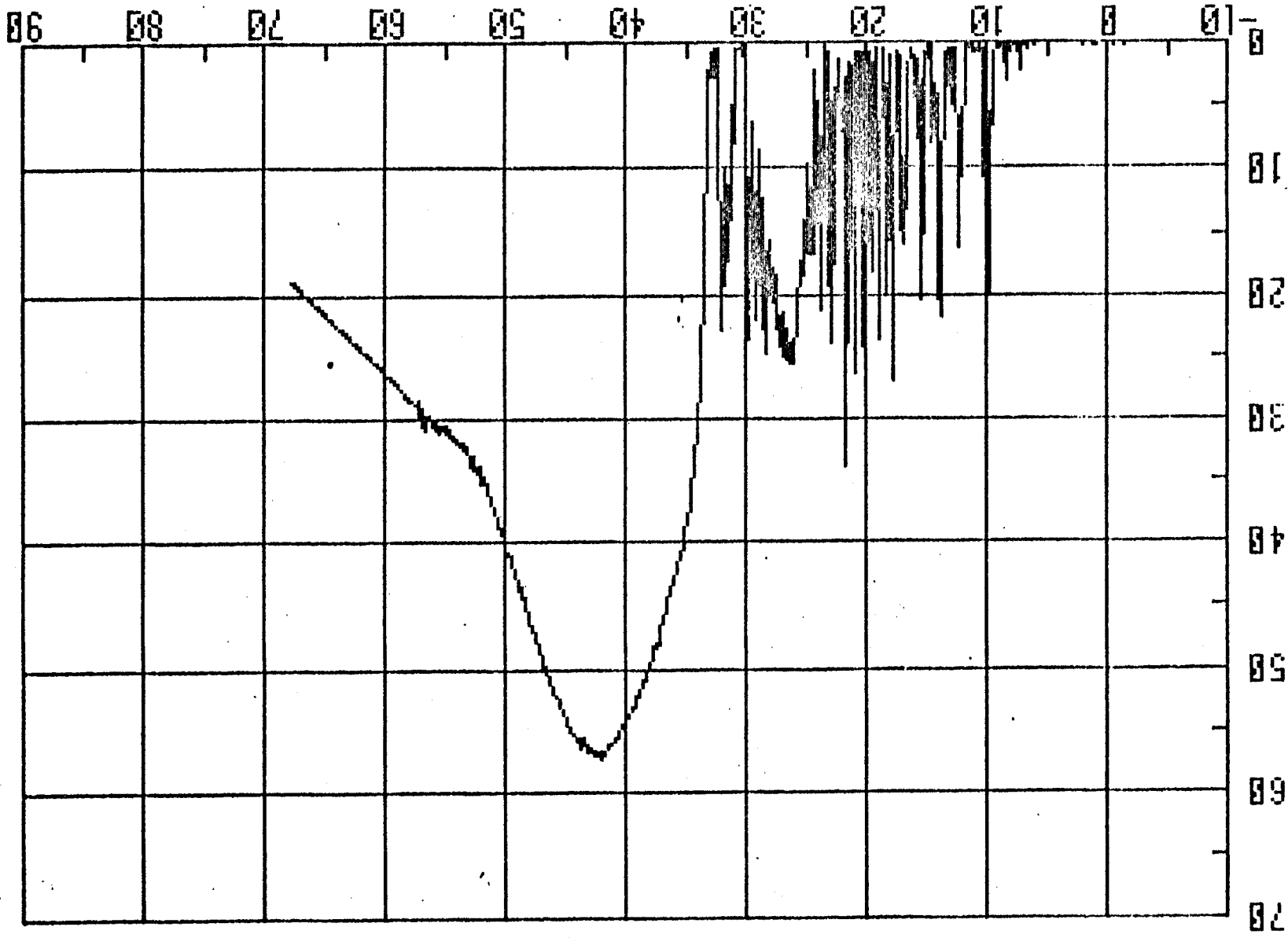
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Sample Near (Inches)



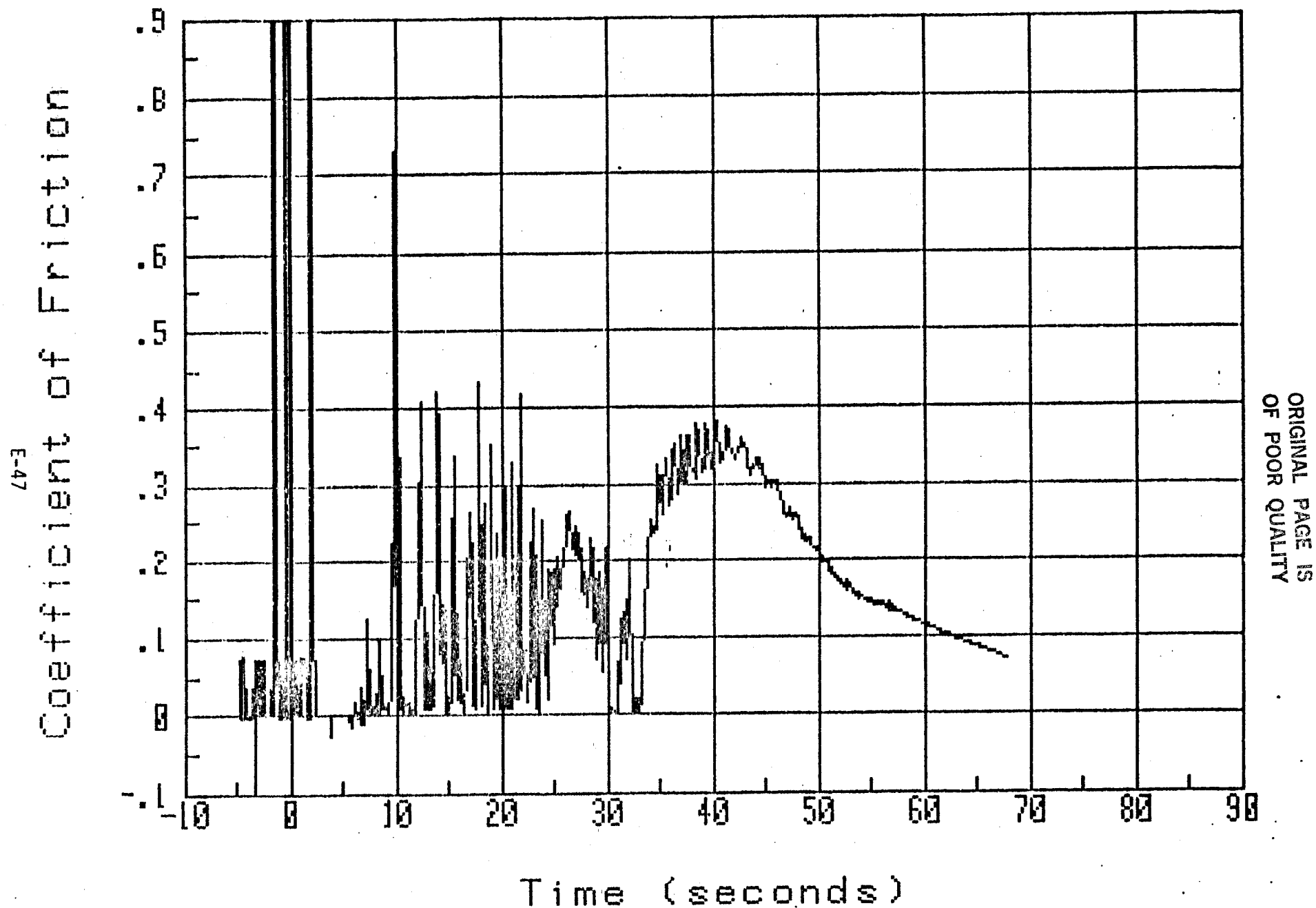
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Torque Load (Lbf)



FRT#259: ZrCu-Stat.: 316 SS-Rot.

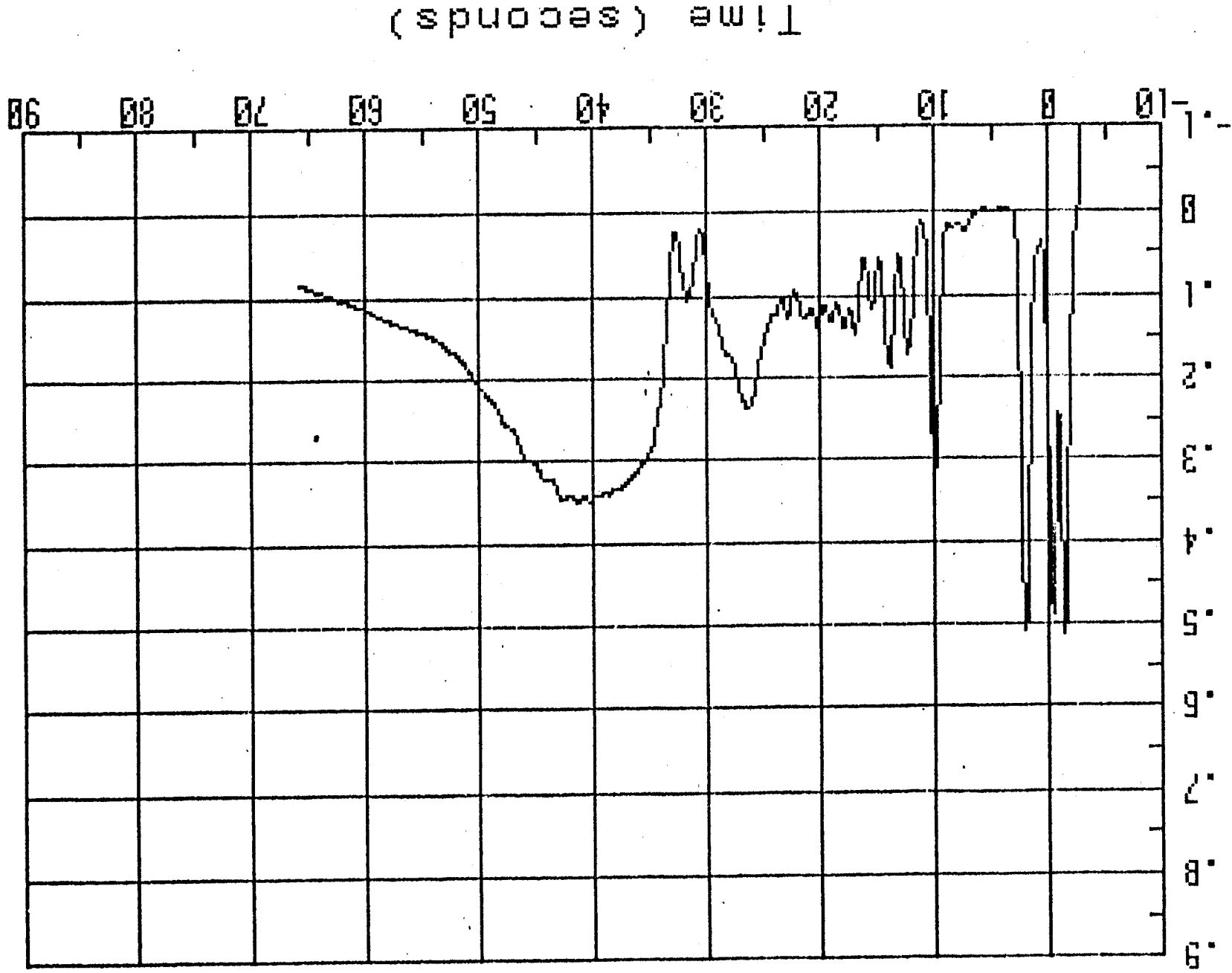
FRT#259: ZrCu-Stat.; 316 SS-Rot.



Contains a torque load and a normal load offset.

E-48

Filtered Coefficient of Friction

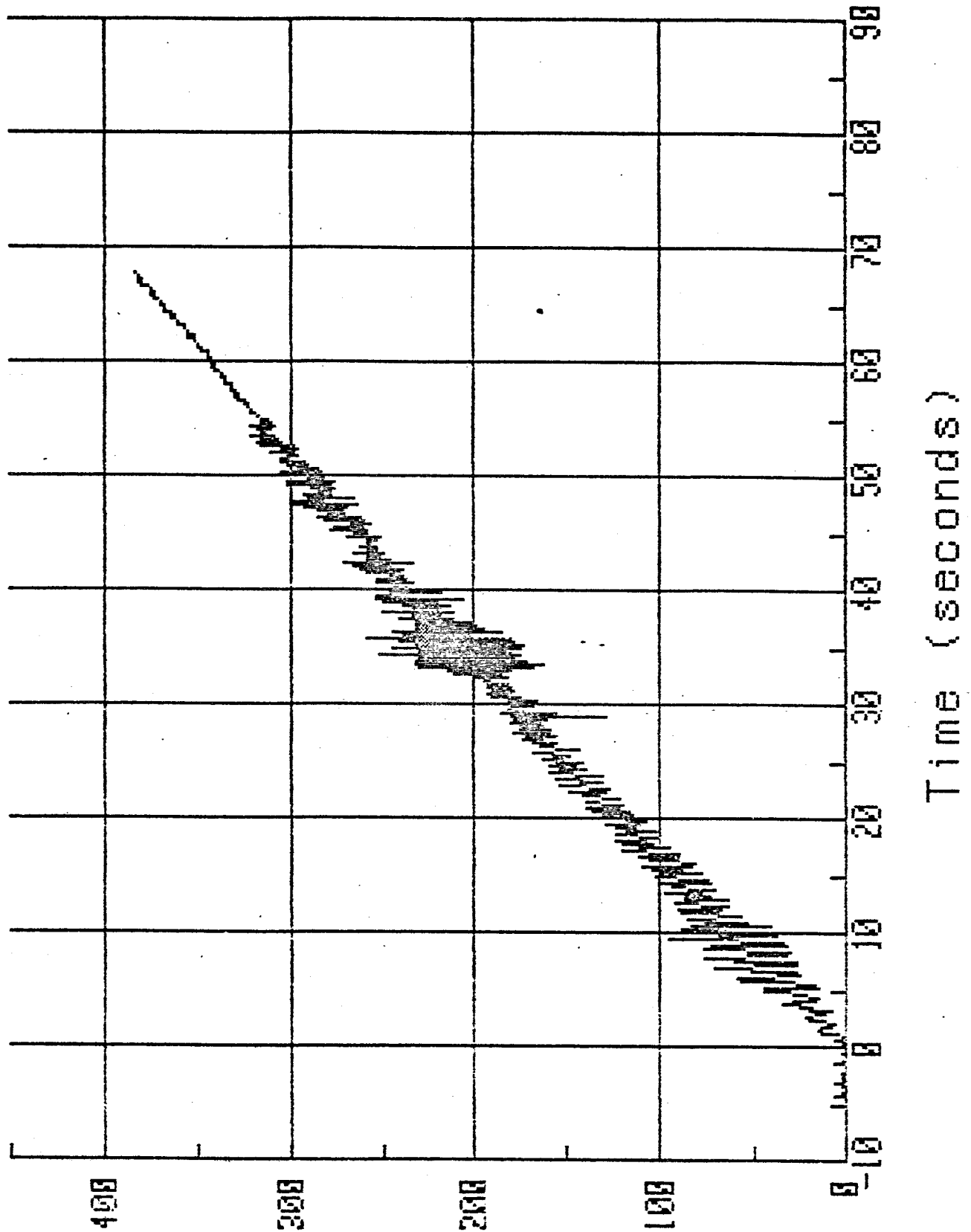


FRT#259: ZrCu-Stat.: 316 SS-Rot.

Contains a torque load and a normal load offset.

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OF POOR QUALITY

FRT#260: Mon. K500-Stat.; 316 SS-Rot.



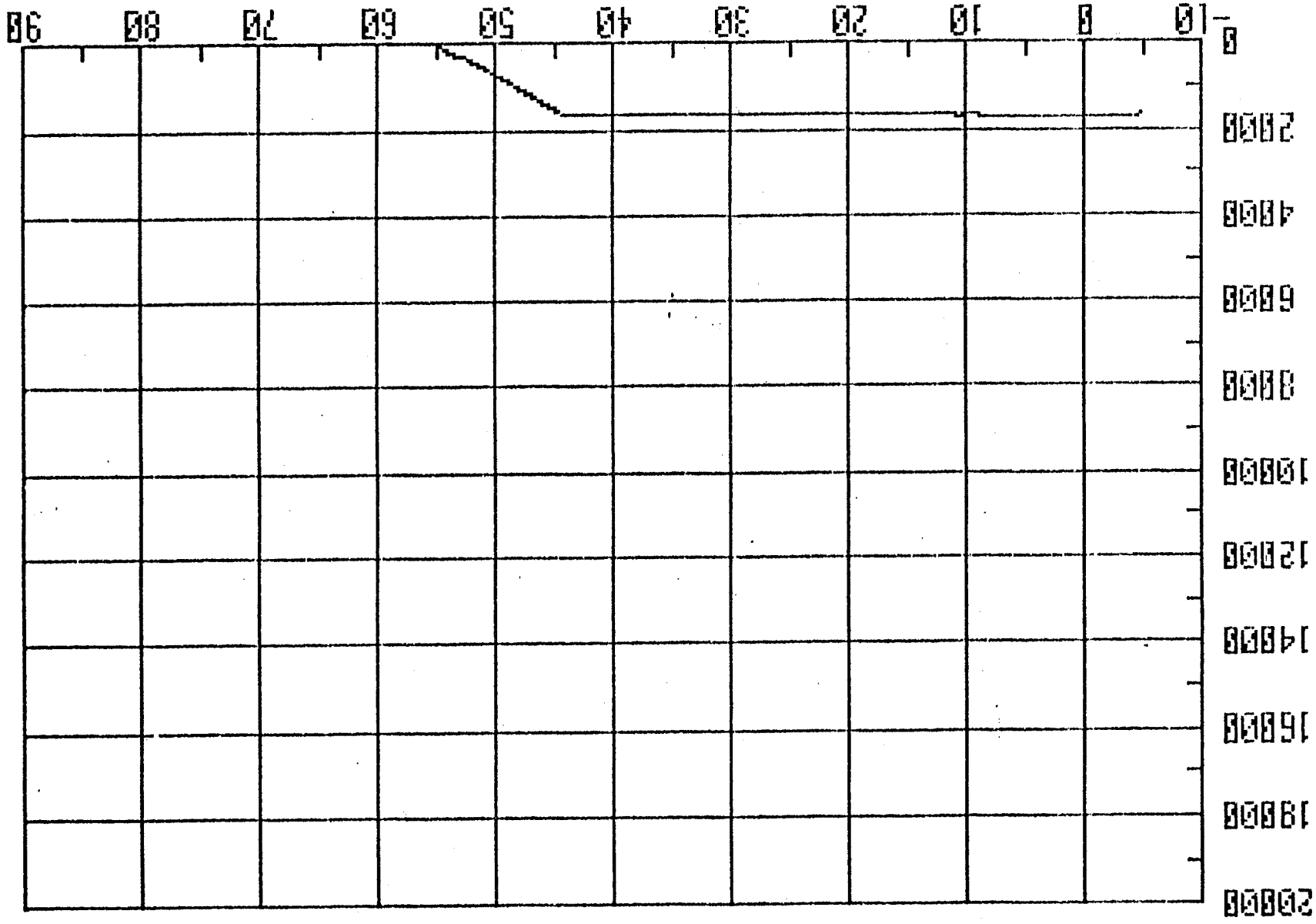
Normal Load (Lbf)

E-49

Contains a -12.3 load offset.

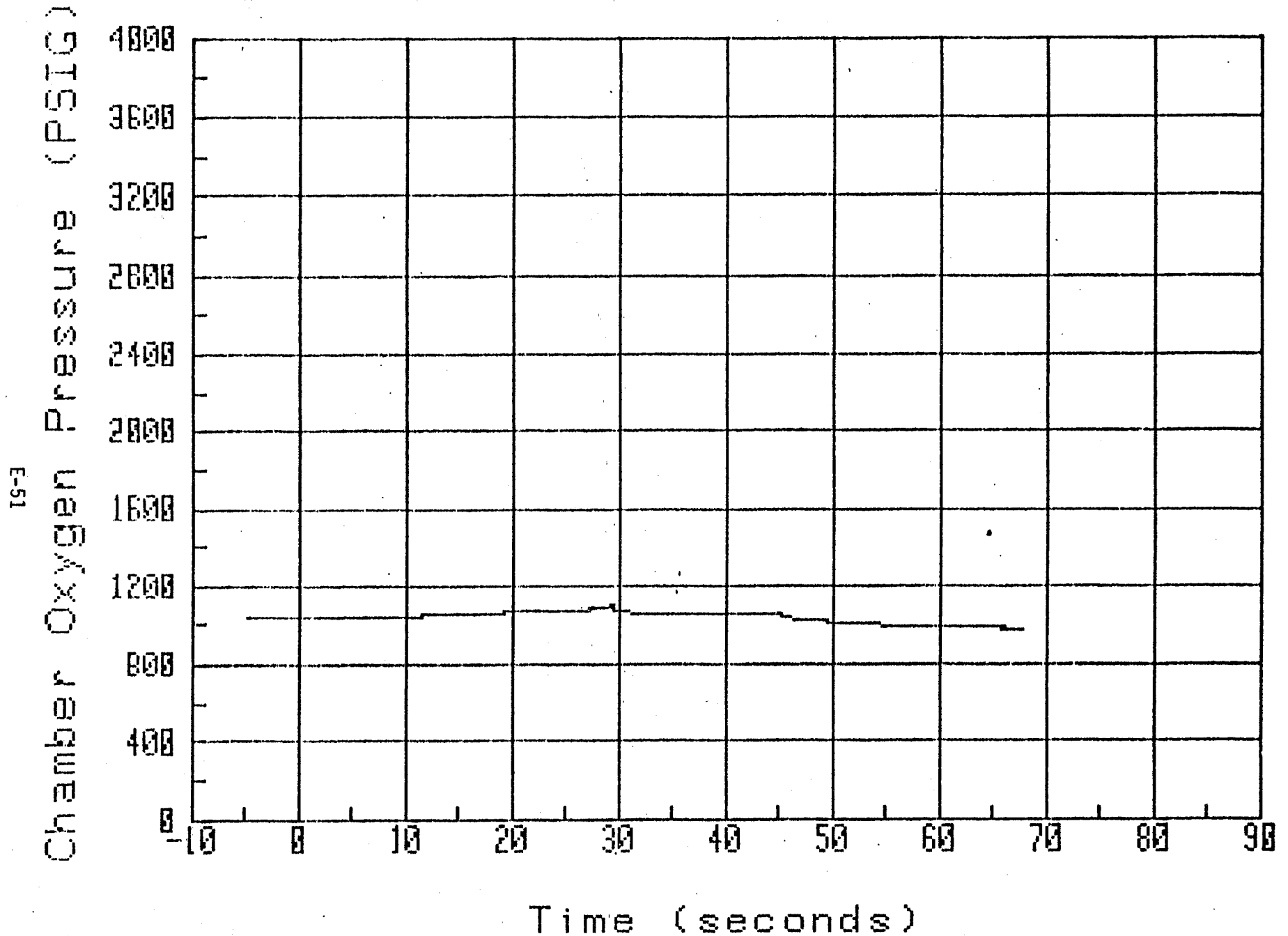
E-50

Revolutions Per Minute

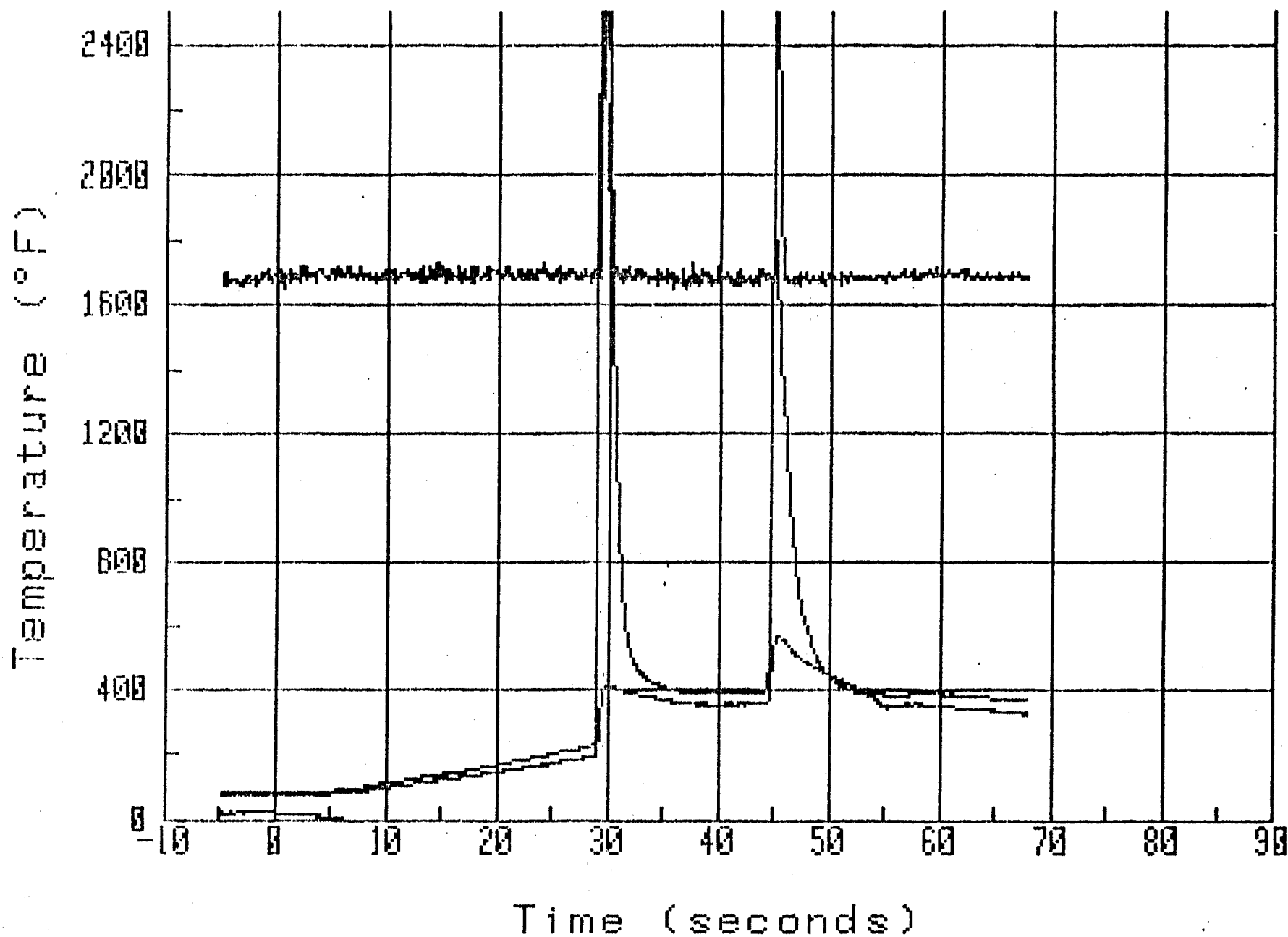


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FRT#260: Mon. K500-Stat.; 316 SS-Rot.



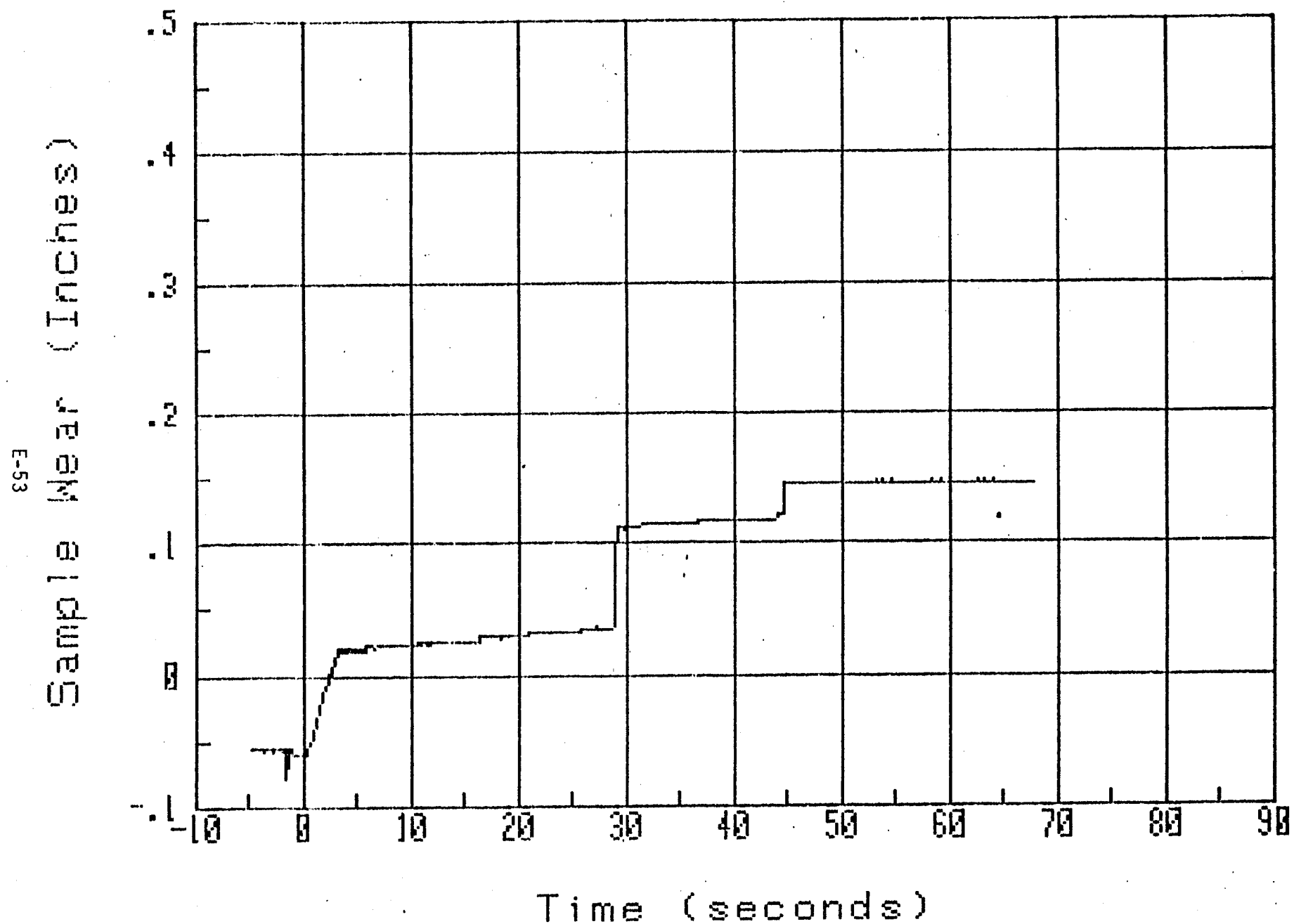
FRT#260: Mon. K500-Stat.; 316 SS-Rot.



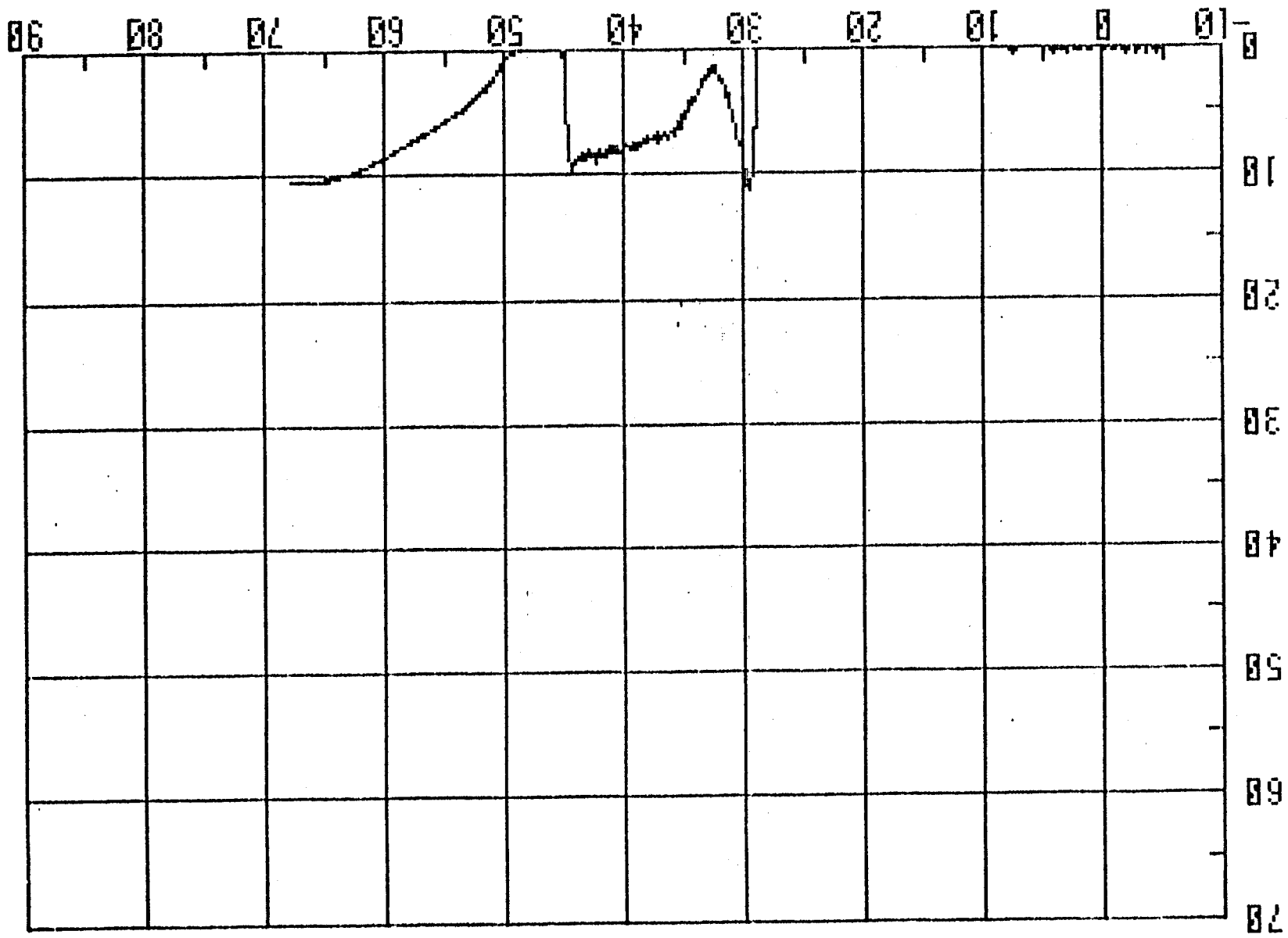
E-52

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FRT#260: Mon. K500-Stat.; 316 SS-Rot.



FRT#260: Mon. K500-Stat.: 316 SS-Rot.



E-54

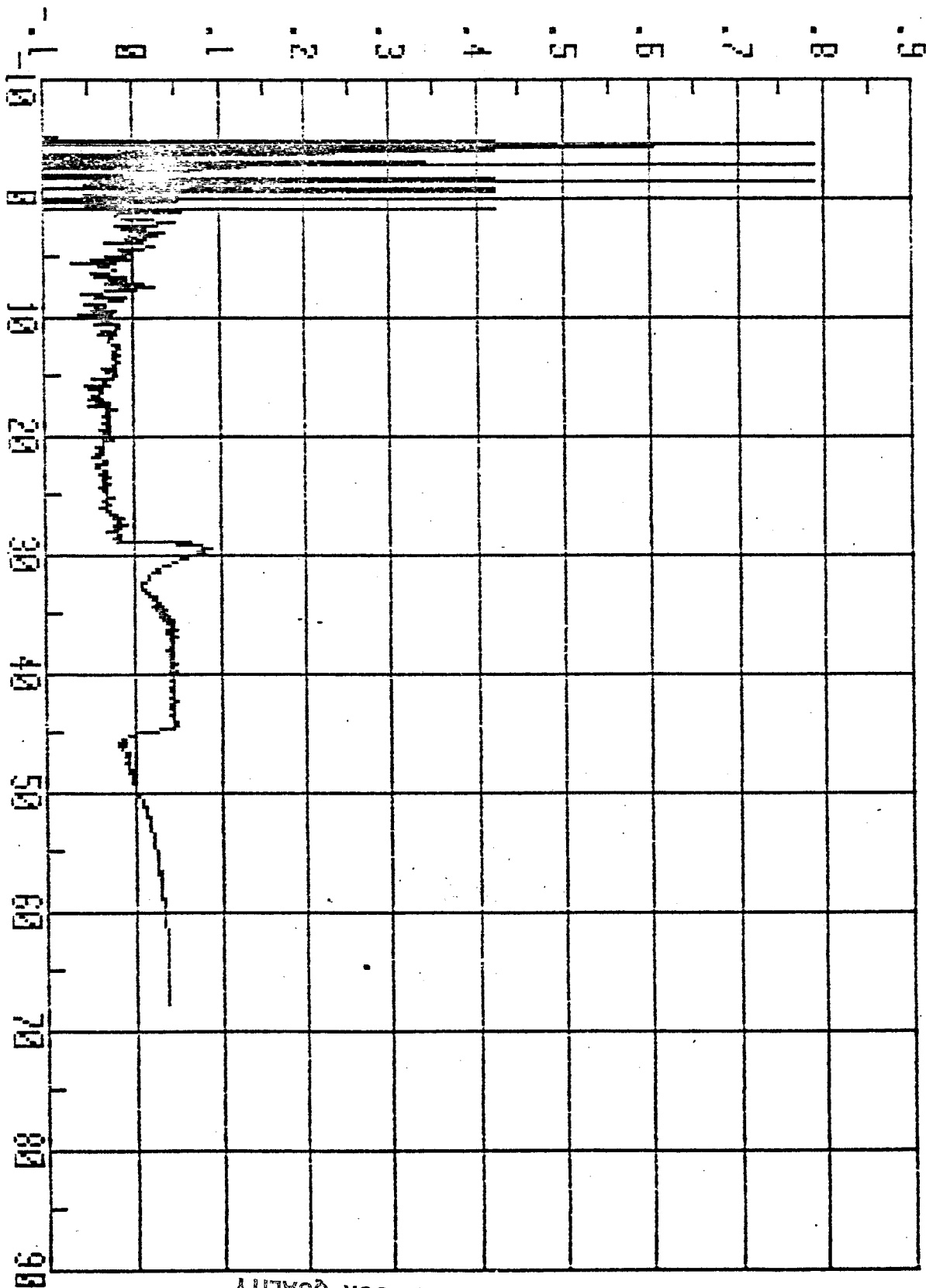
(+97) 2207 enb301

Contains a 14.8 load offset.

Time (seconds)

Coefficient of Friction

FRT#250: Mon. K500-Stat.; 316 SS-Rot.

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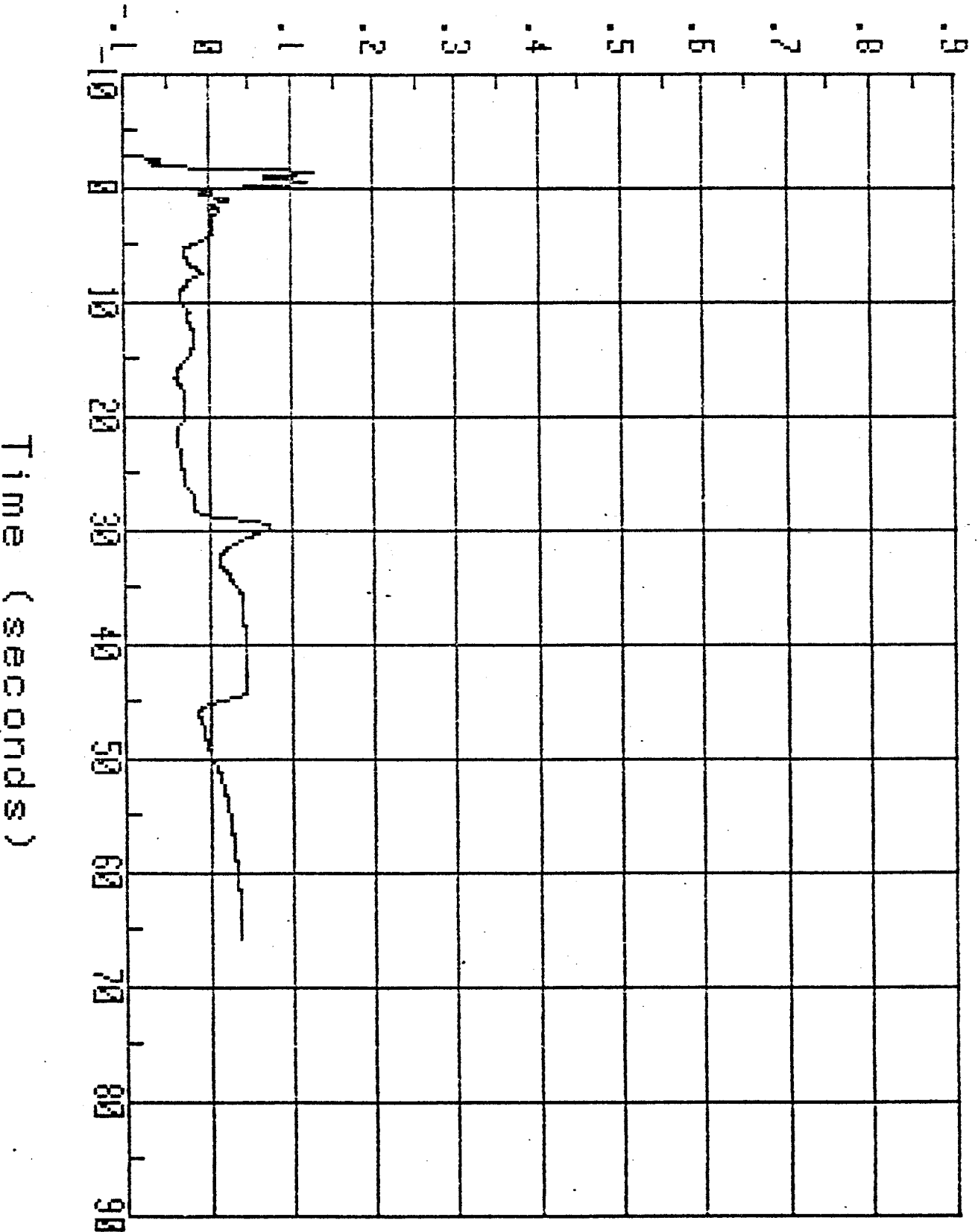
Contains a torque load and a normal load offset.

FRT#260: Mon. K500-Stat.; 316 SS-Rot.

Filtered Coefficient of Friction

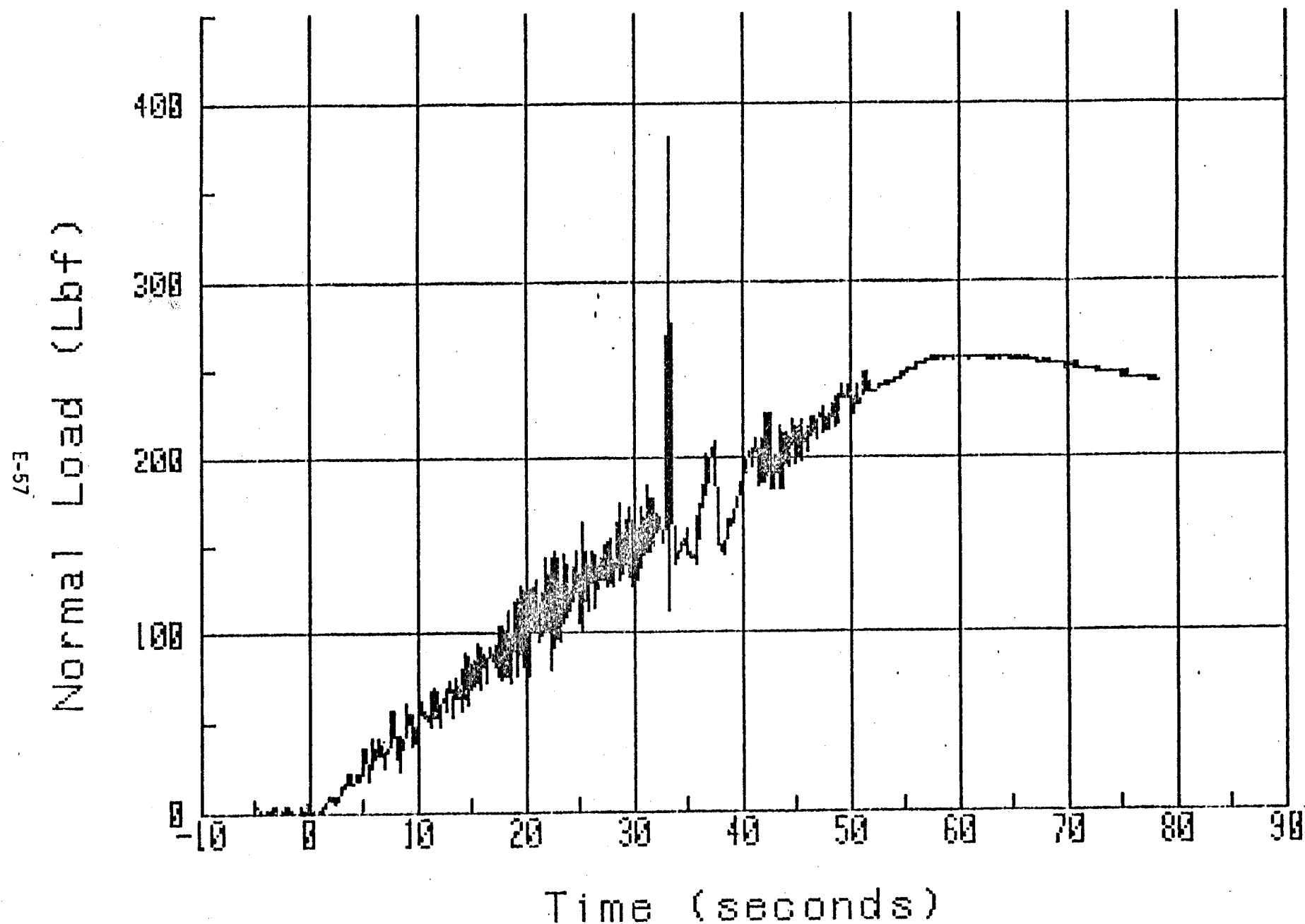
E-56

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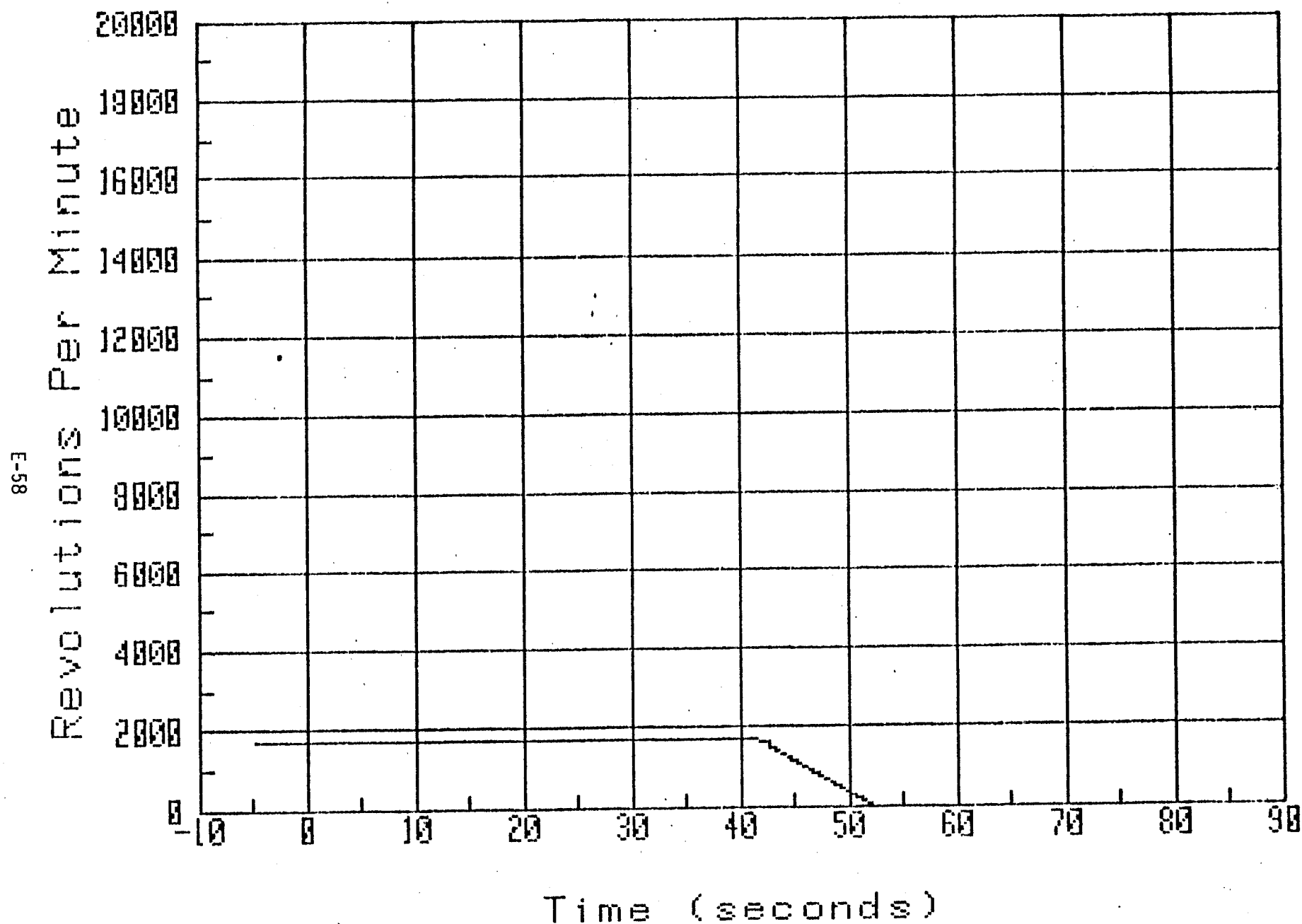
Contains a torque load and a normal load offset.

FRT#261: Mon. K500-Stat.; 316 SS-Rot.

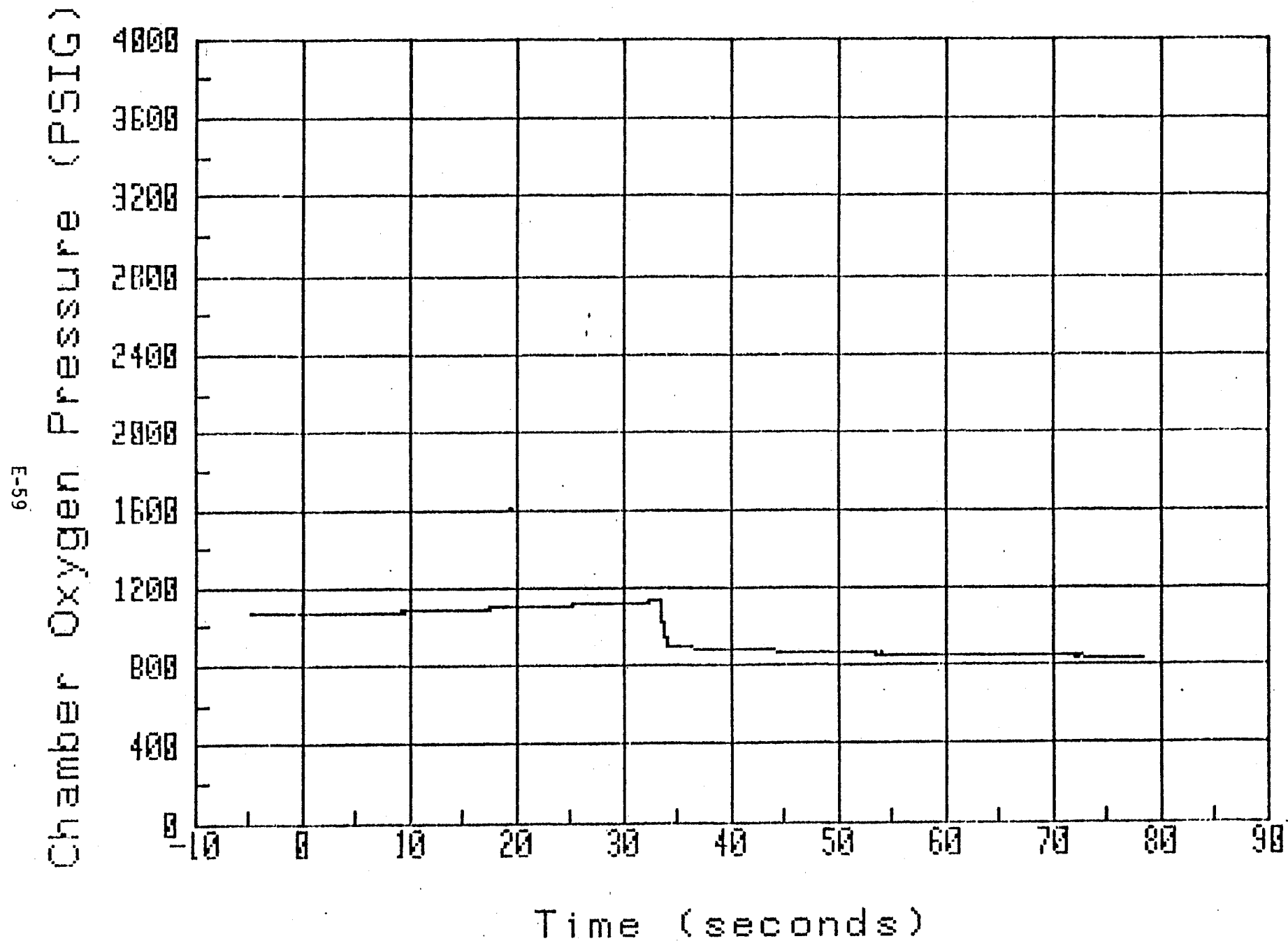


Contains a -0.5 load offset.

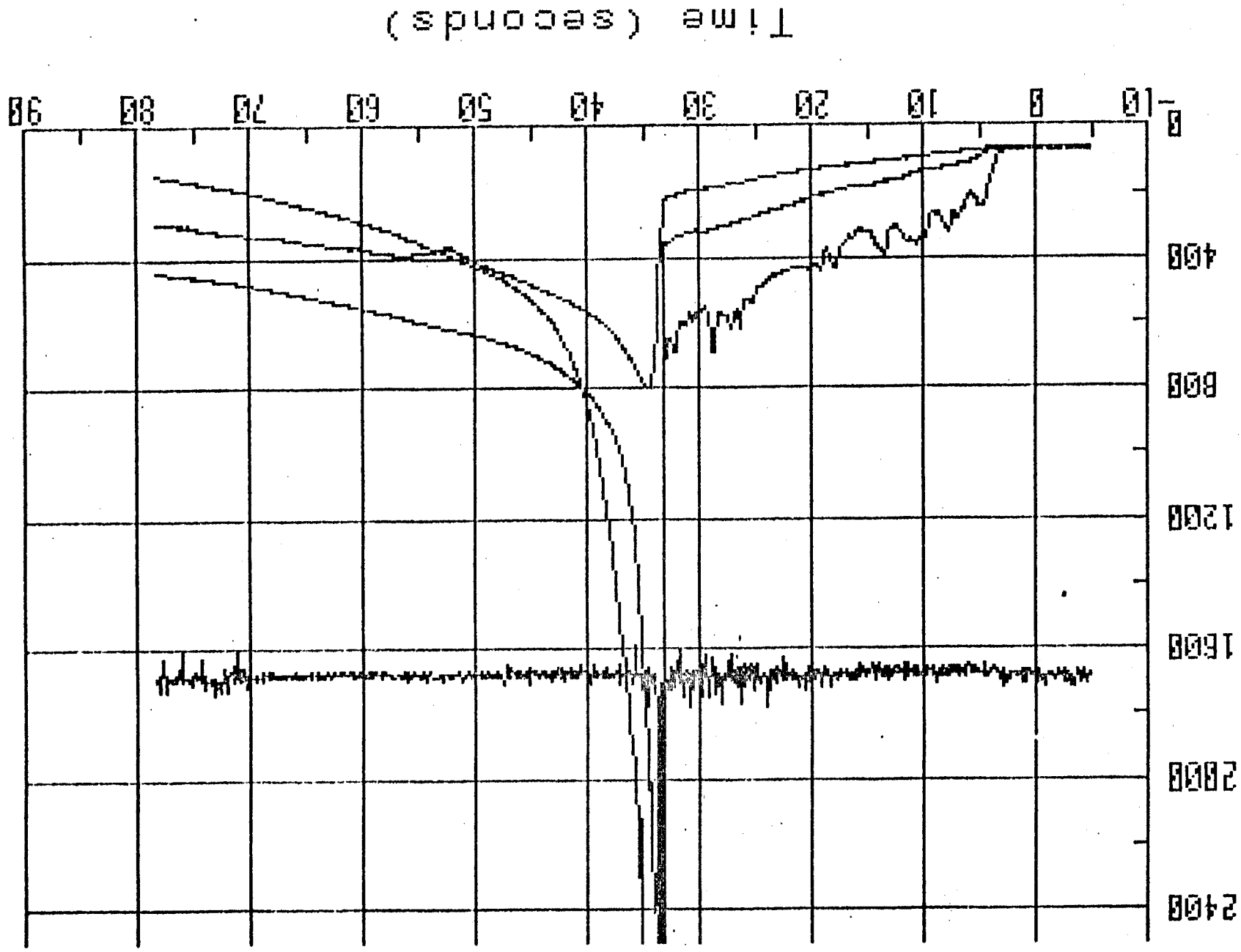
FRT#261: Mon. K500-Stat.; 316 SS-Rot.



FRT#261: Mon. K500-Stat.; 316 SS-Rot.



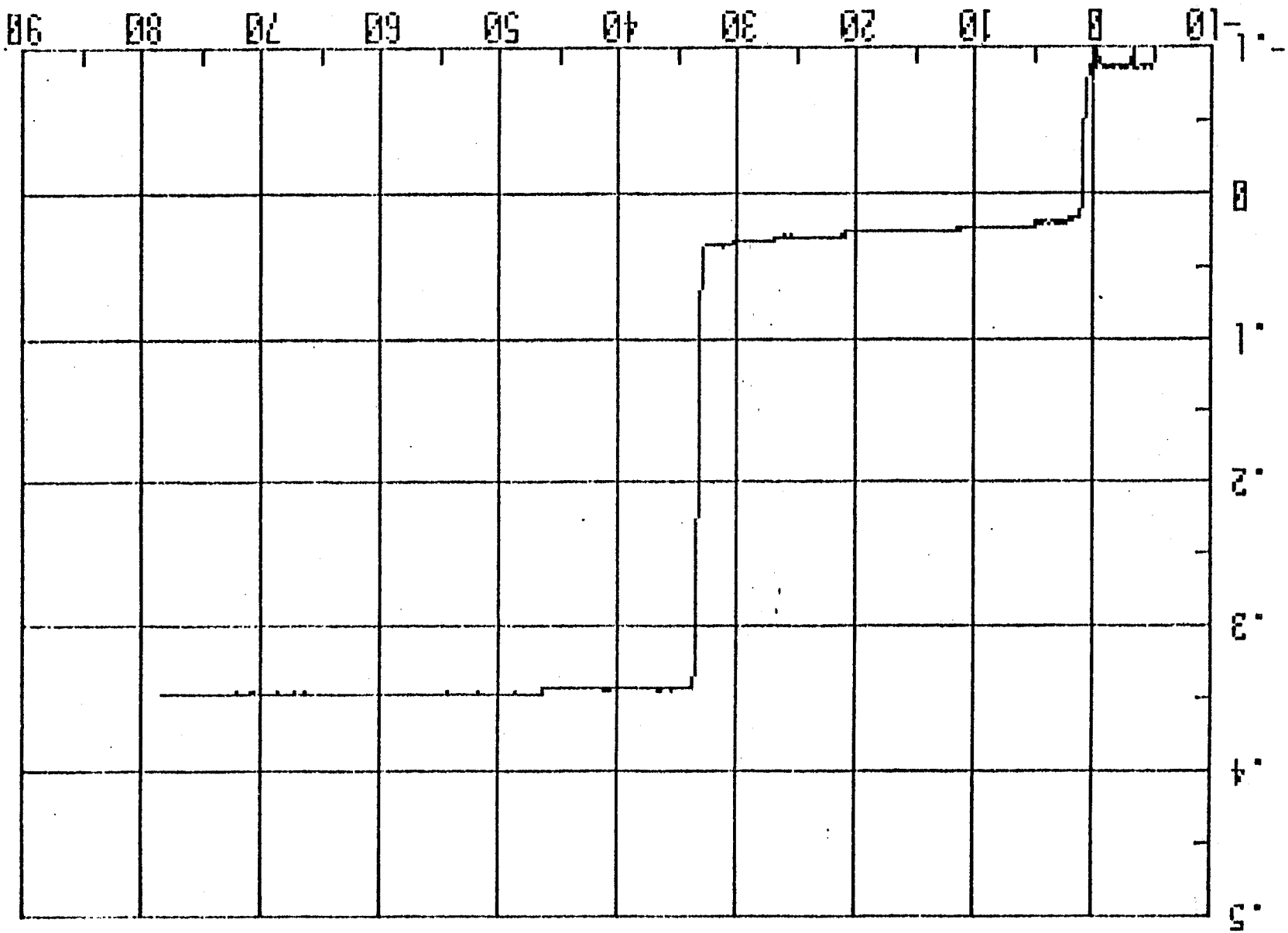
Temperature (°F)



FRT#261: Mon. K500-Stat.; 316 SS-Rot.

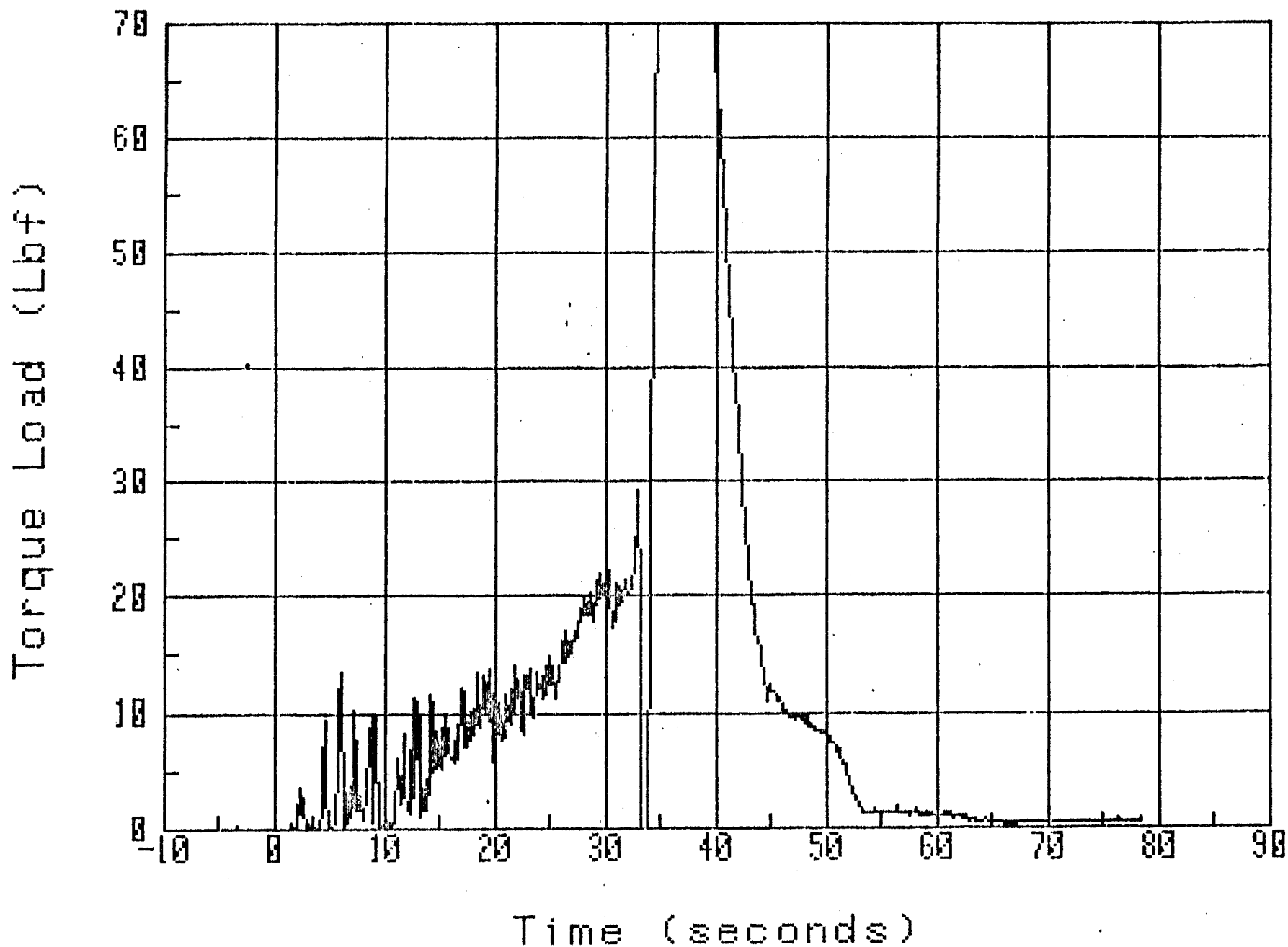
E-61

Sample Wear (Inches)



FRT#261: Mon. K500-Stat.; 316 SS-Rot.

FRT#261: Mon. K500-Stat.; 316 SS-Rot.

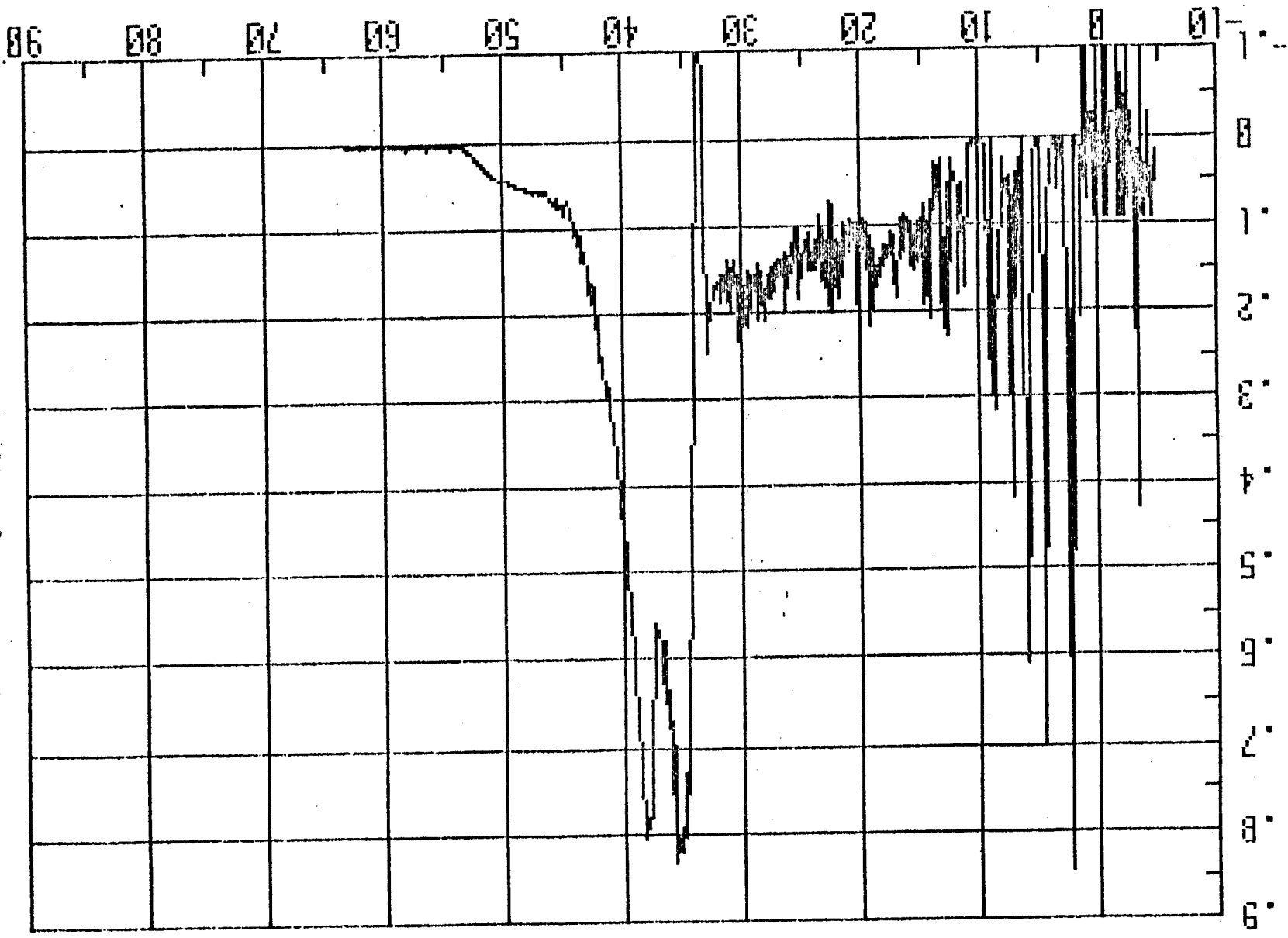


E-62

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Contains a +.7 load offset.

Coefficient of Friction



FRT#261: Mon. K500-Stat.: 316 SS-Rot.

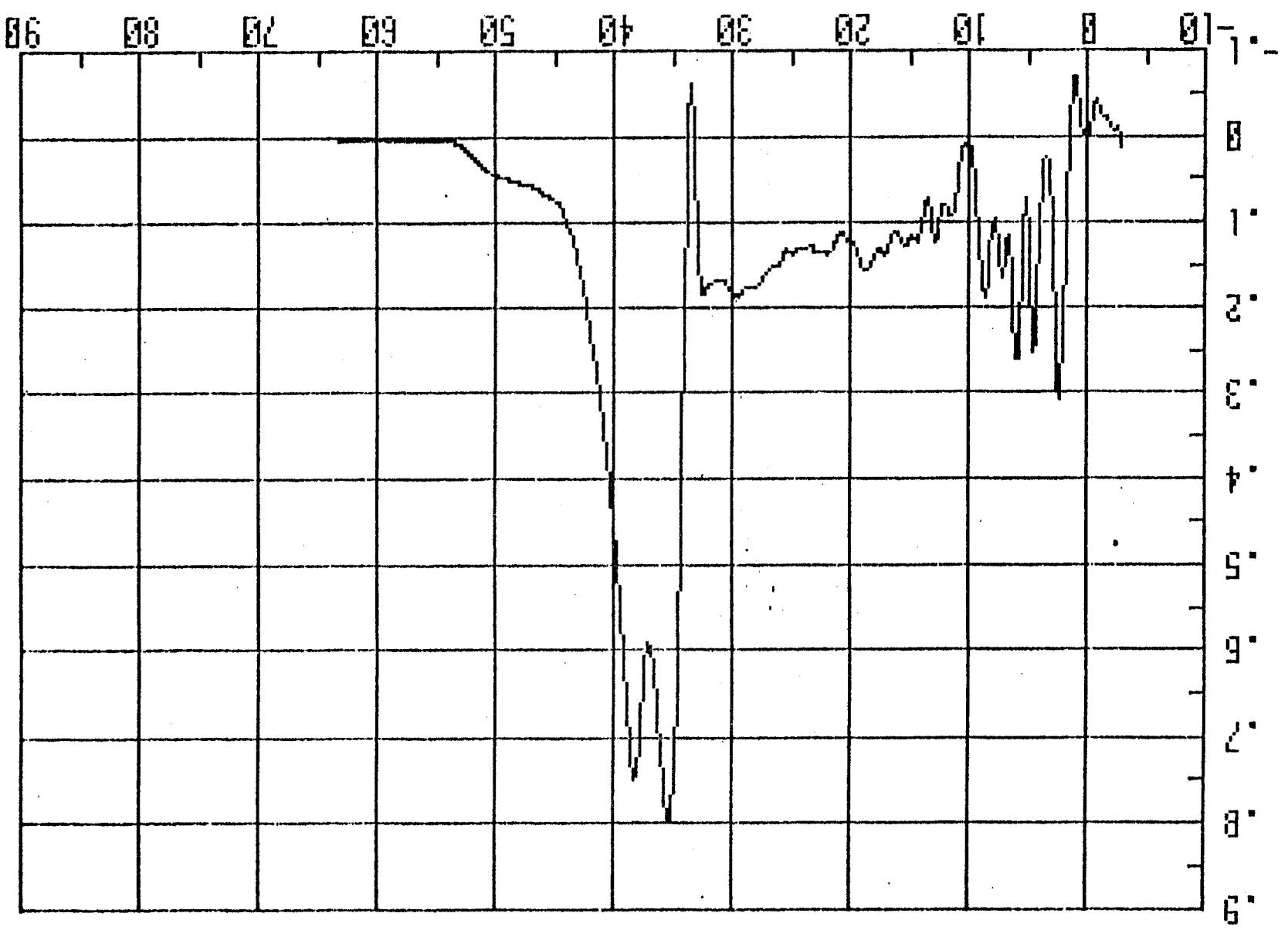
Time (seconds)

Contains a torque load and a normal load offset.

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Filtered Coefficient of Friction

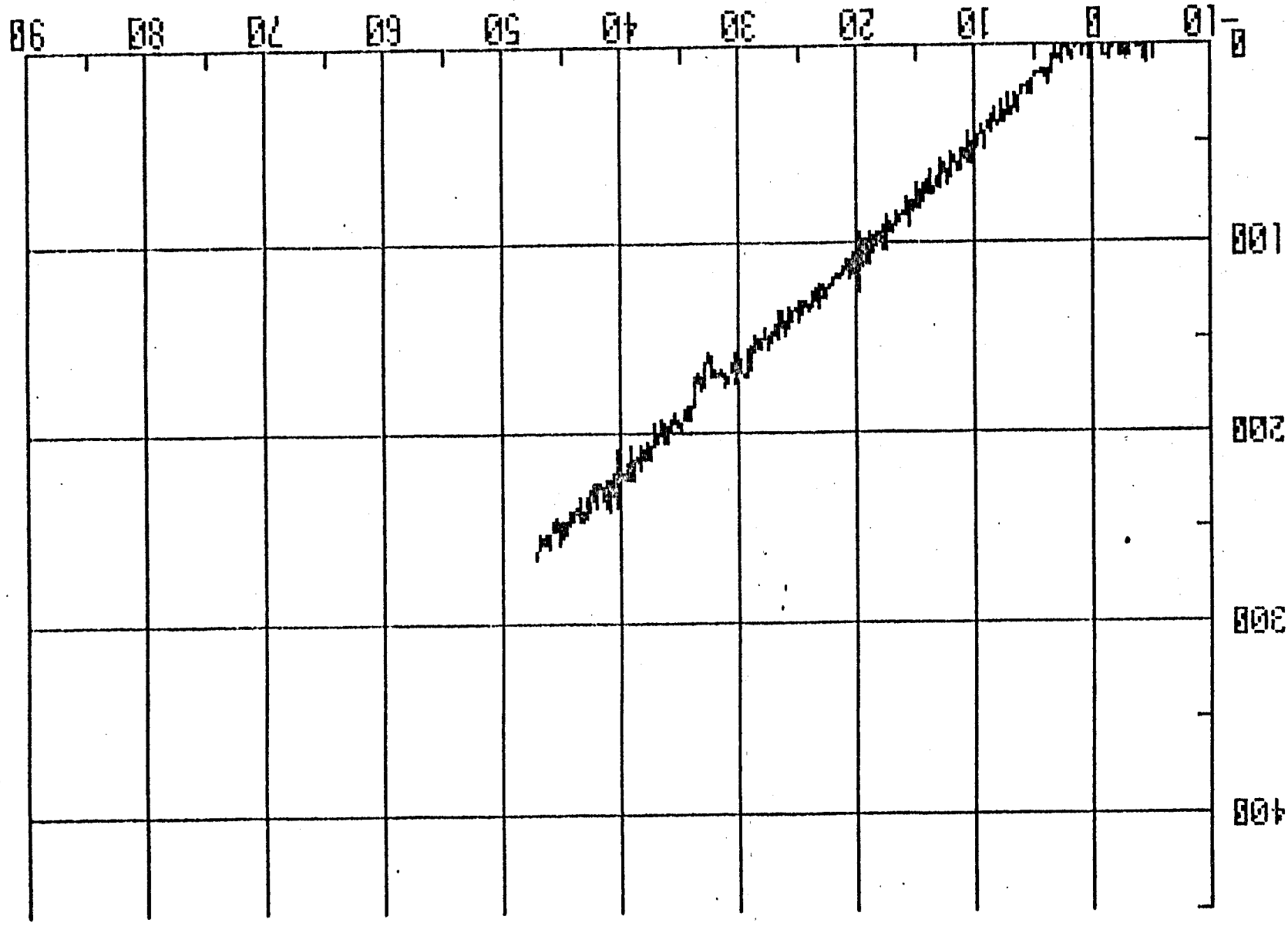
E-64



FRT#261: Mon. K500-Stat.: 316 SS-Rot.

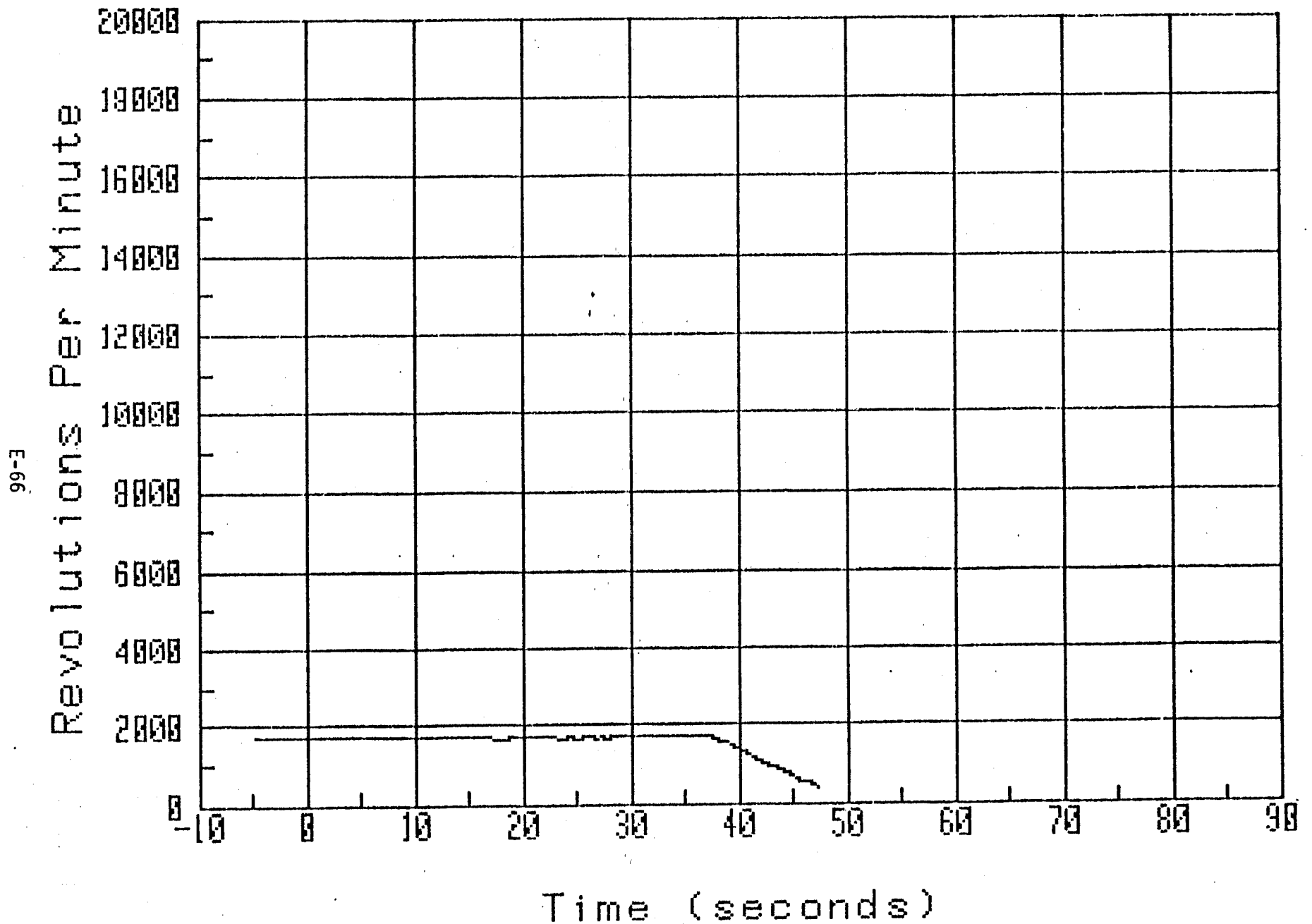
Contains a torque load and a normal load offset.

Normal Load (Lbf)

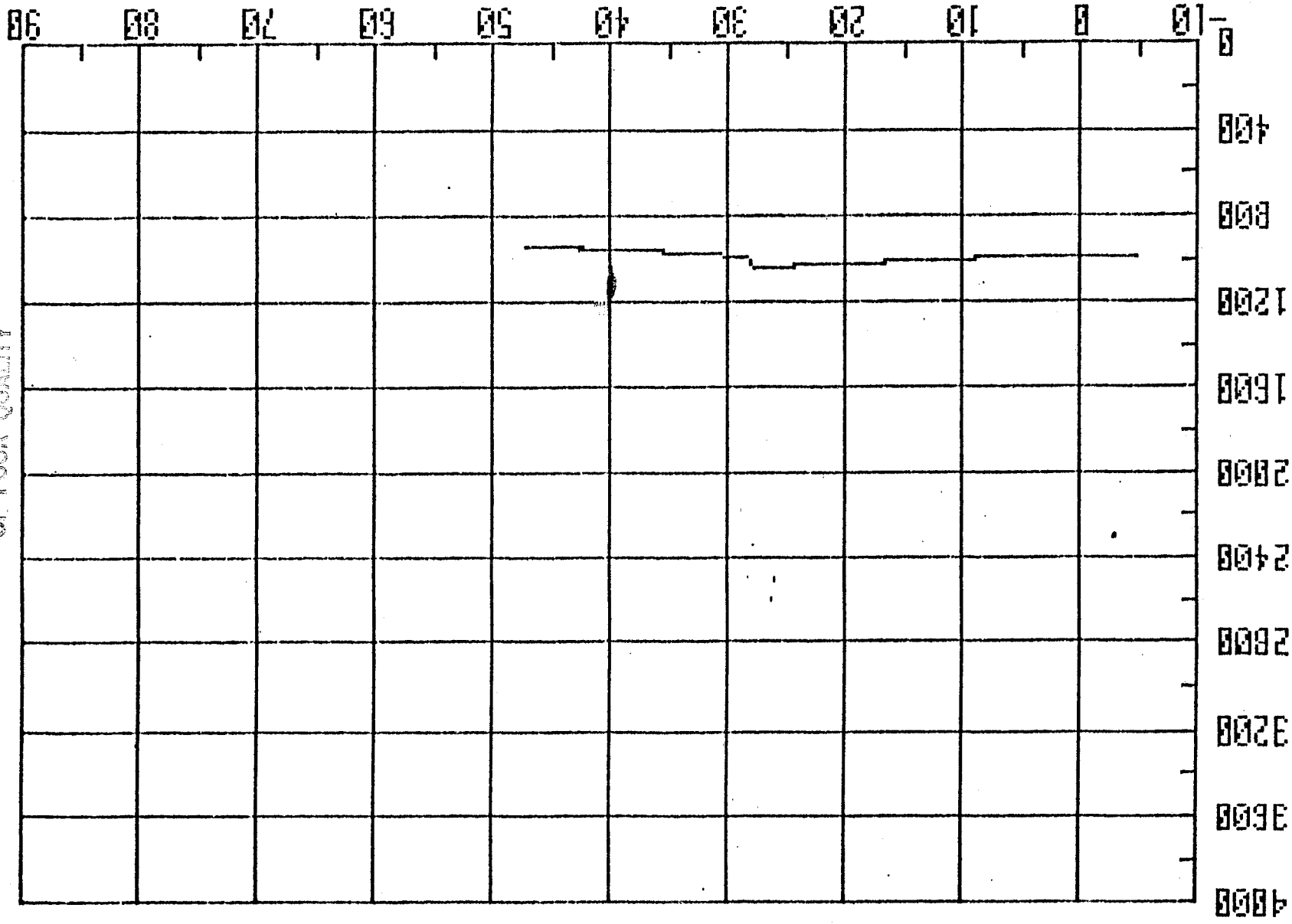


FRT#262: Mon. K500-Stat.: 316 SS-Rot.

FRT#262: Mon. K500-Stat.; 316 SS-Rot.

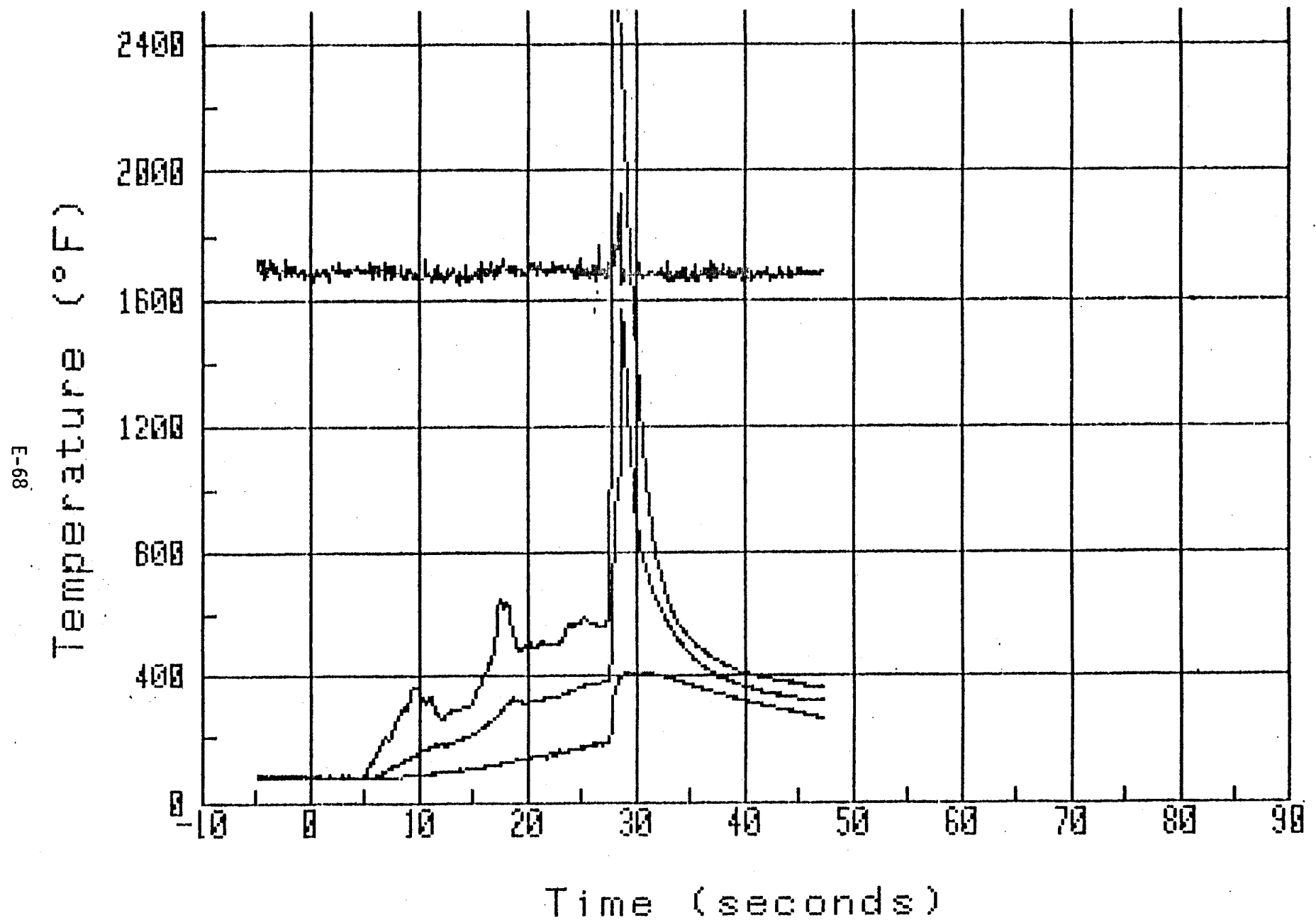


Chamber Oxygen Pressure (PSIG)

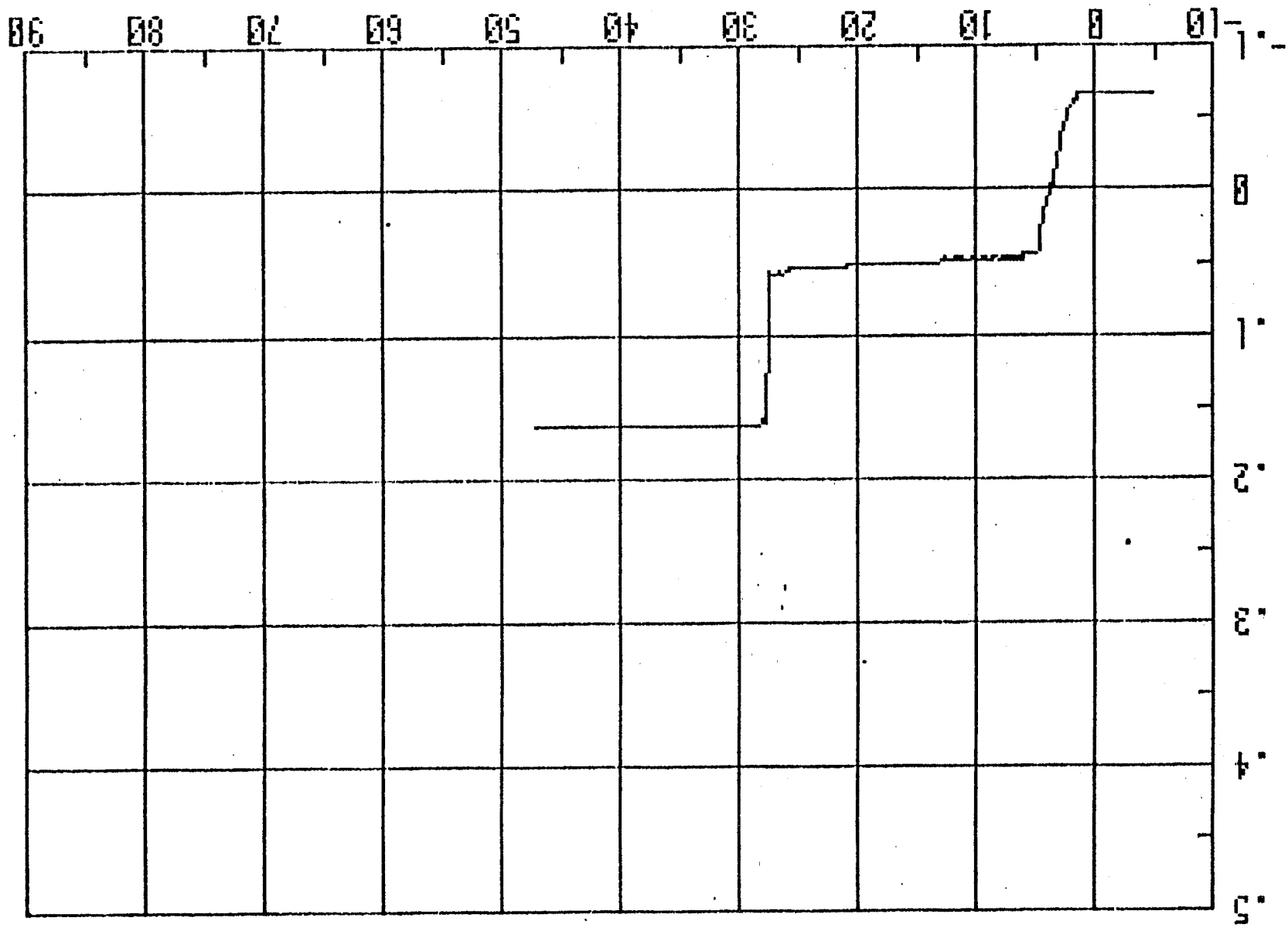


FRT#262: Mon. K500-Stat.: 316 SS-Rot.

FRT#262: Mon. K500-Stat.; 316 SS-Rot.



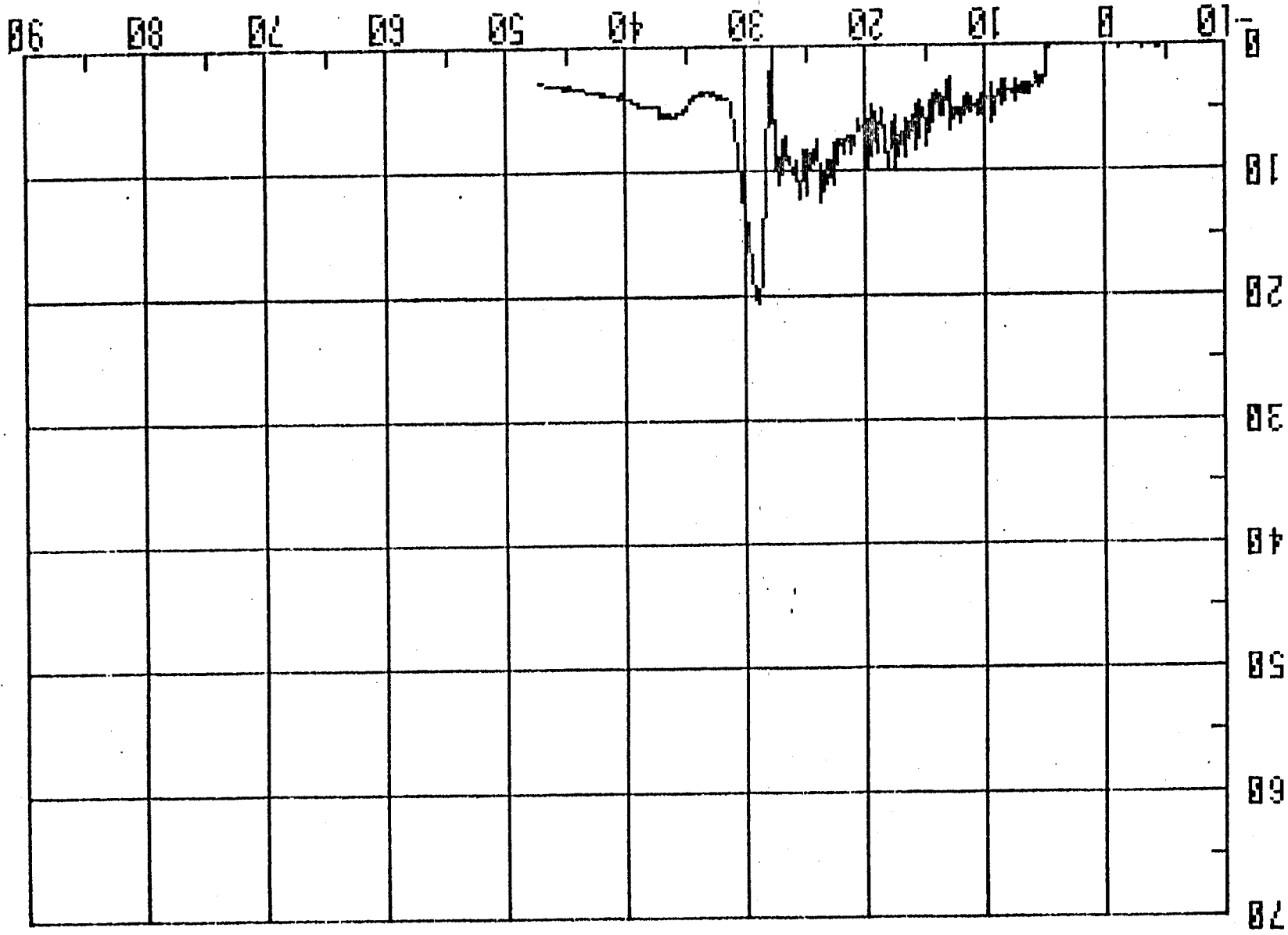
Sample Wear (Inches)



FRT#262: Mon. K500-Stat.: 316 SS-Rot.

E-70

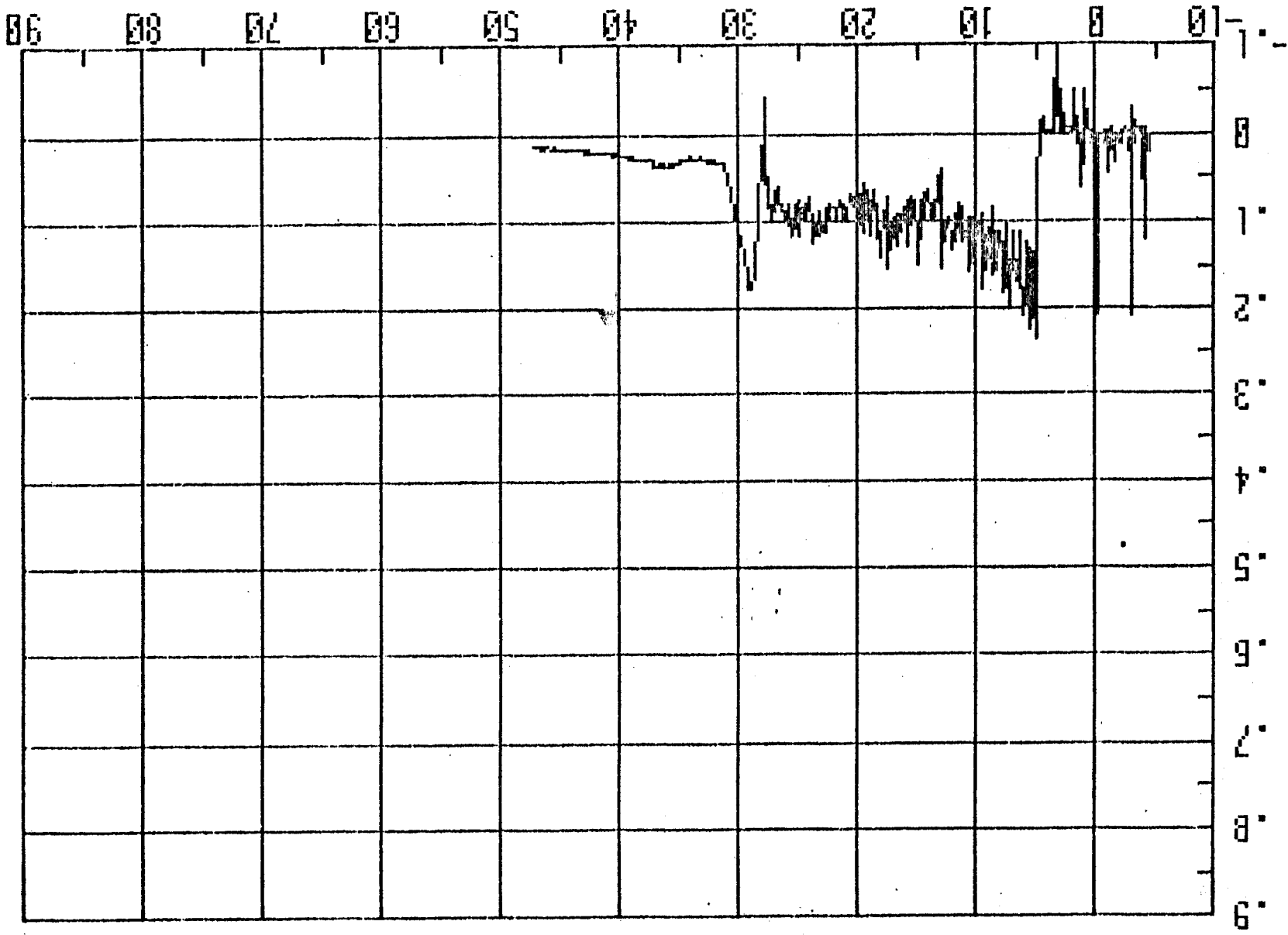
Torque Load (Lbf)



FRT#262: Mon. K500-Stat.; 316 SS-Rot.

Contains 2 +.8 load offset.

Coefficient of Friction

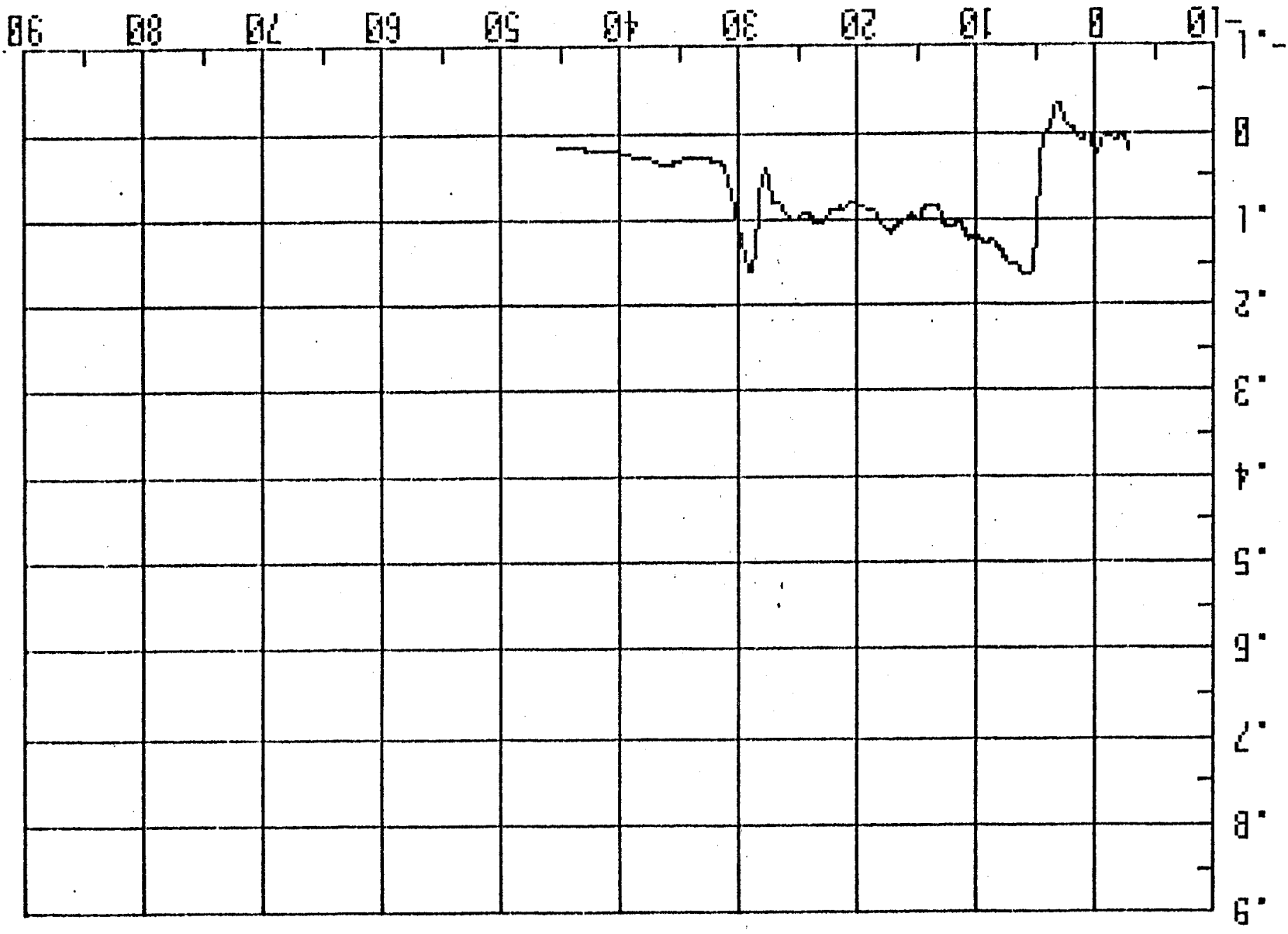


FRT#262: Mon. K500-Stat.: 316 SS-Rot.

Contains a torque load and a normal load offset.

Time (seconds)

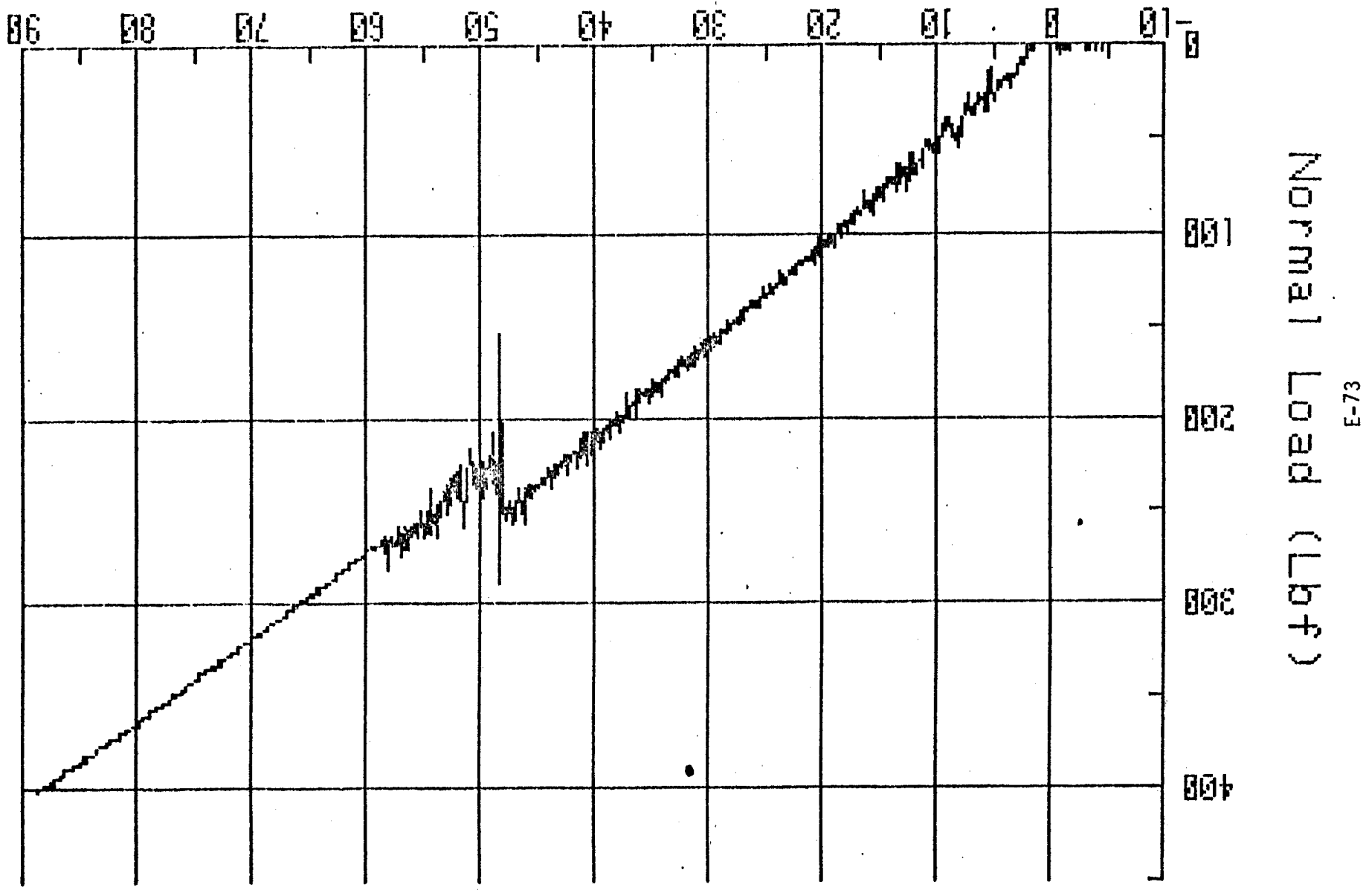
Filtered Coefficient of Friction



FRT#262: Mon. K500-Stat.: 316 SS-Rot.

Contains a torque load and a normal load offset.

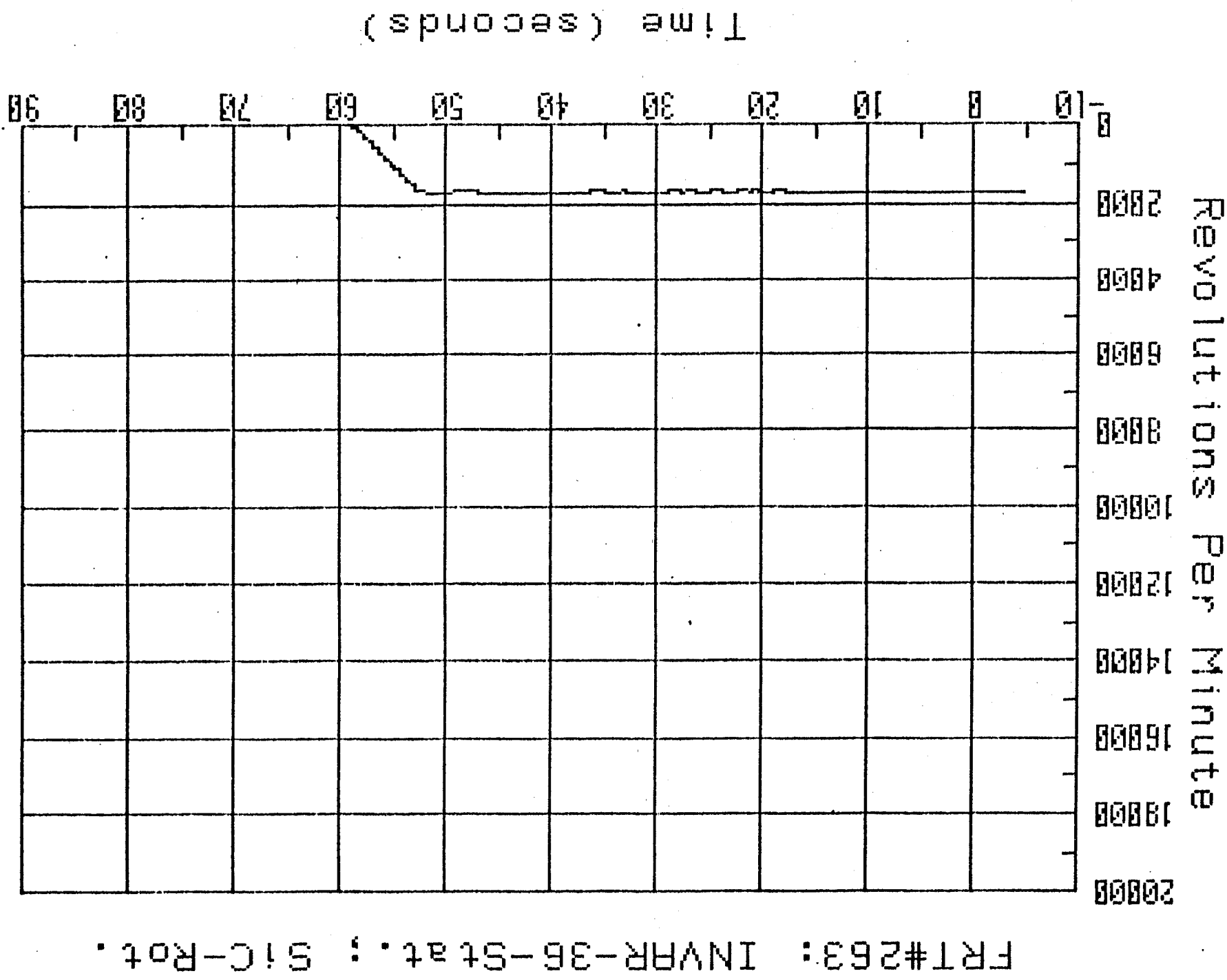
FRT#263: INVAR-36-Stat.; SIC-Rot.



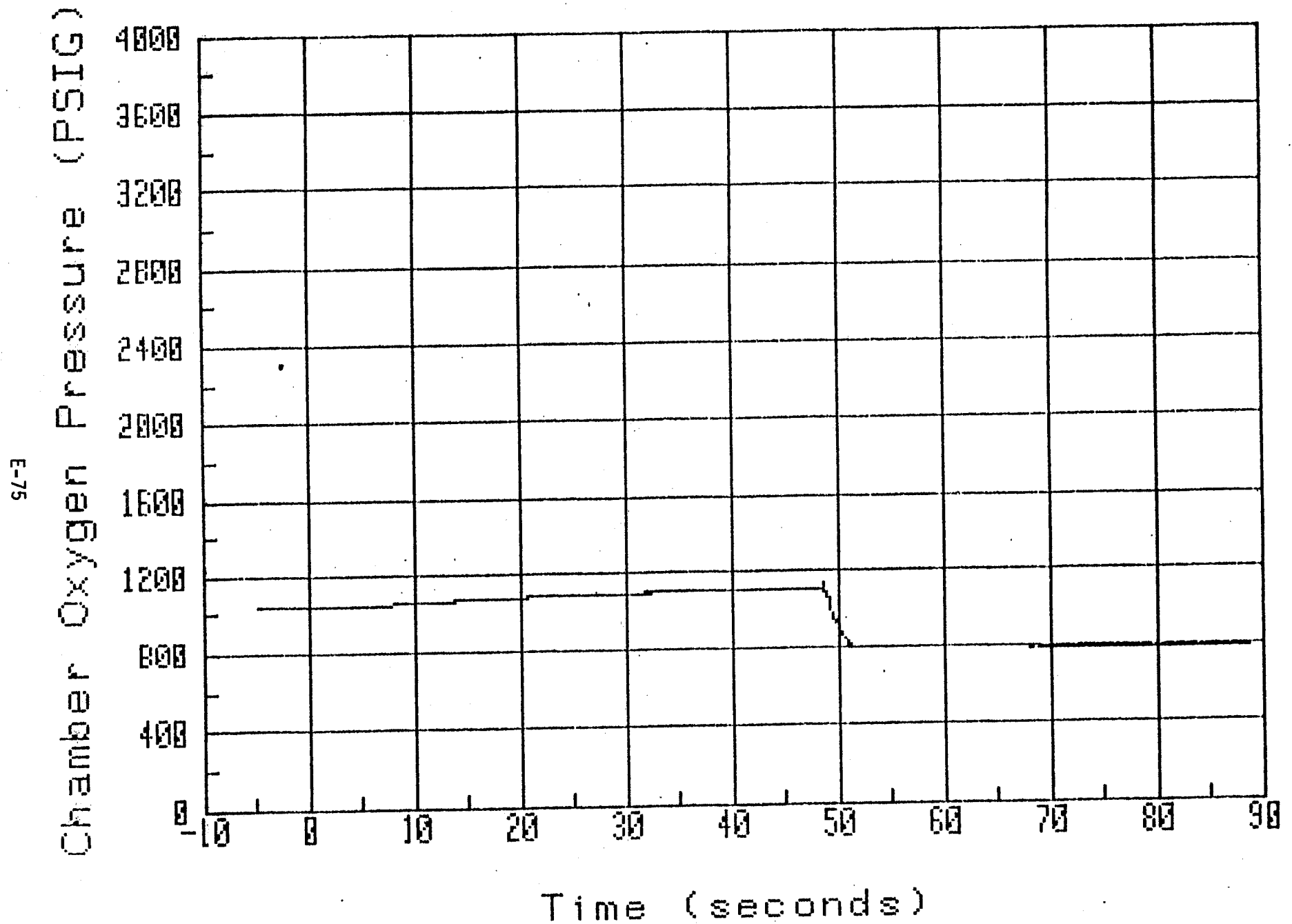
Time (seconds)

Contains a -12.7 load offset.

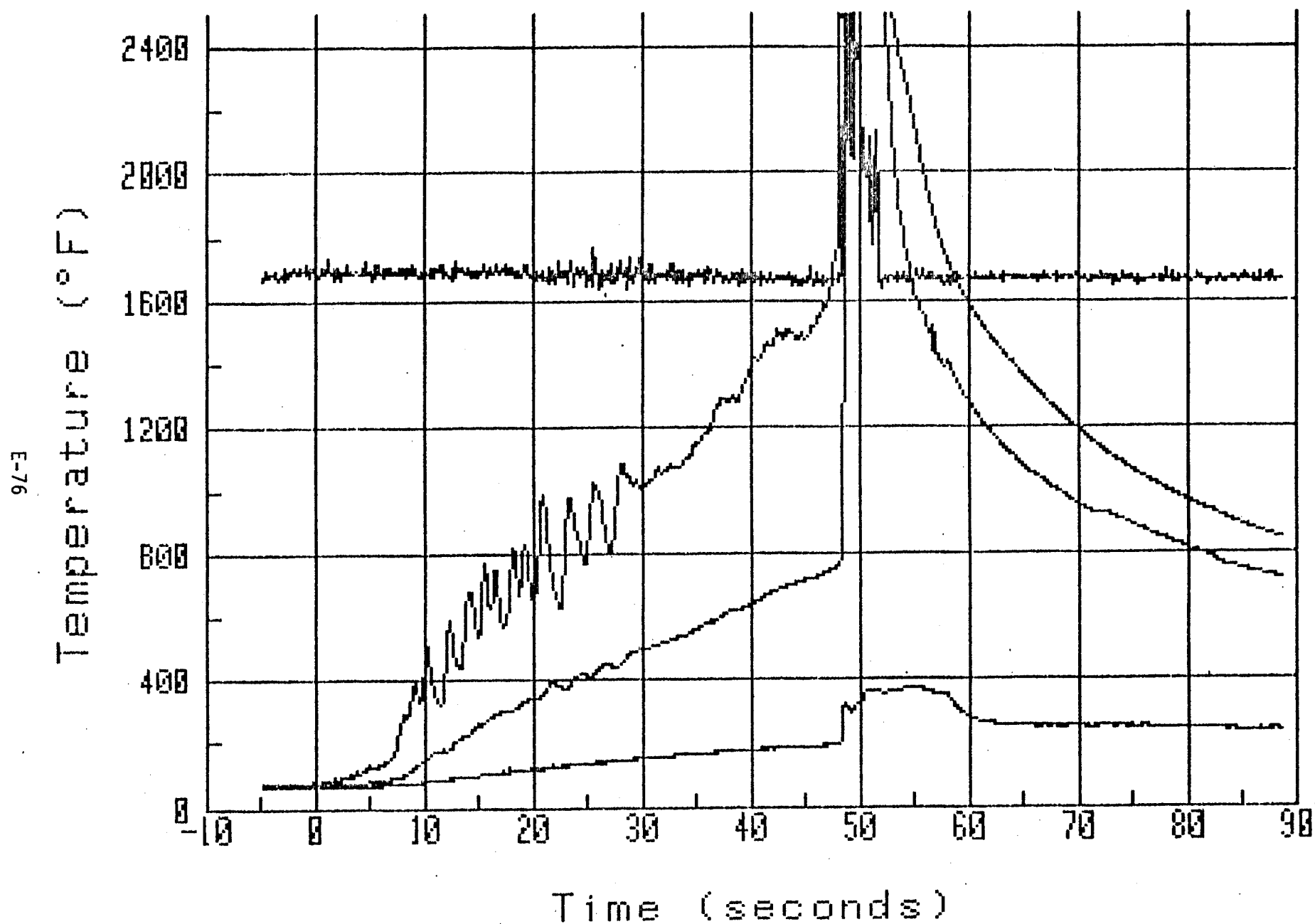
E-74



FRT#263: INVAR-36-Stat.; SiC-Rot.

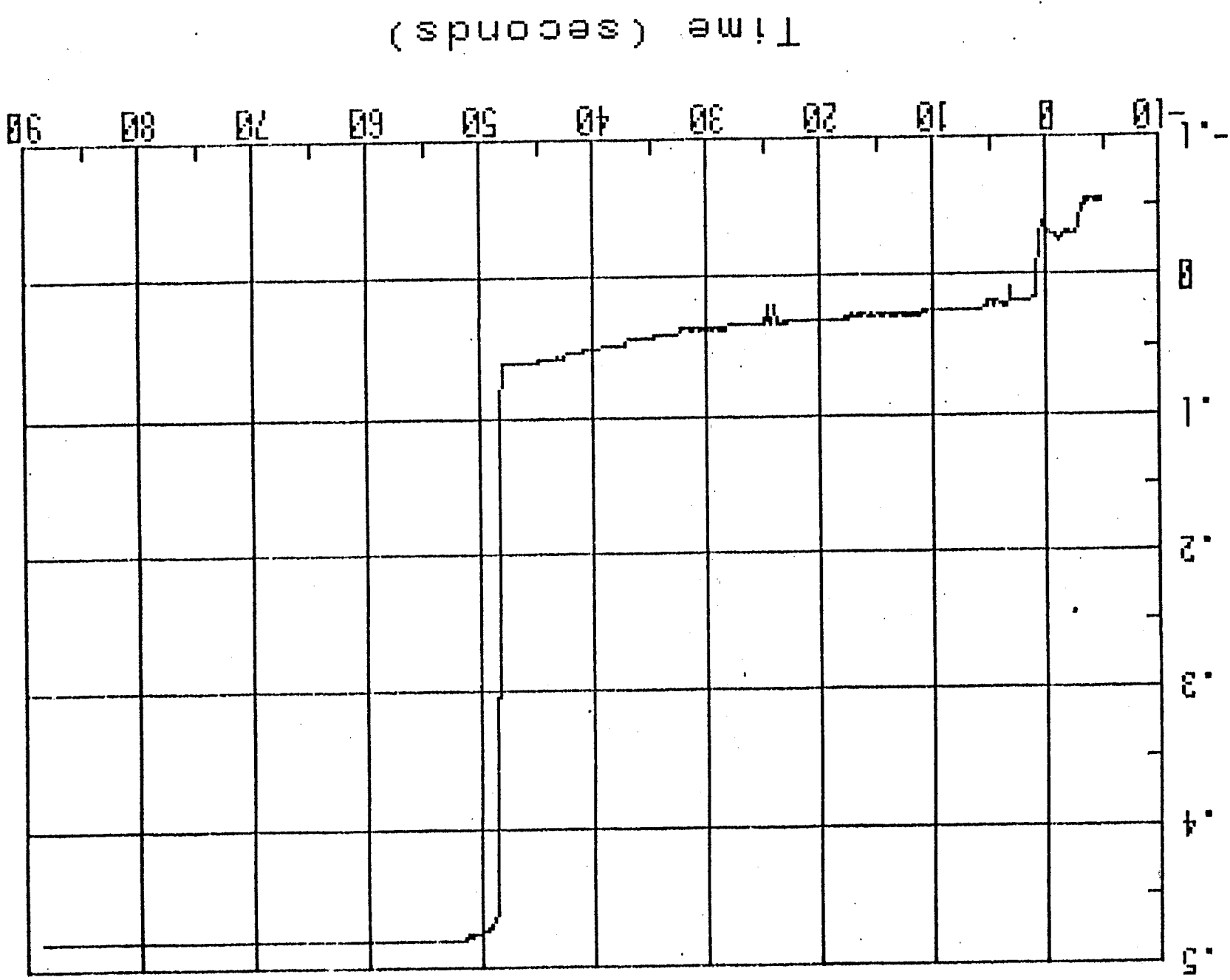


FRT#263: INVAR-36-Stat.; SiC-Rot.



E-77

Sample Wear (Inches)

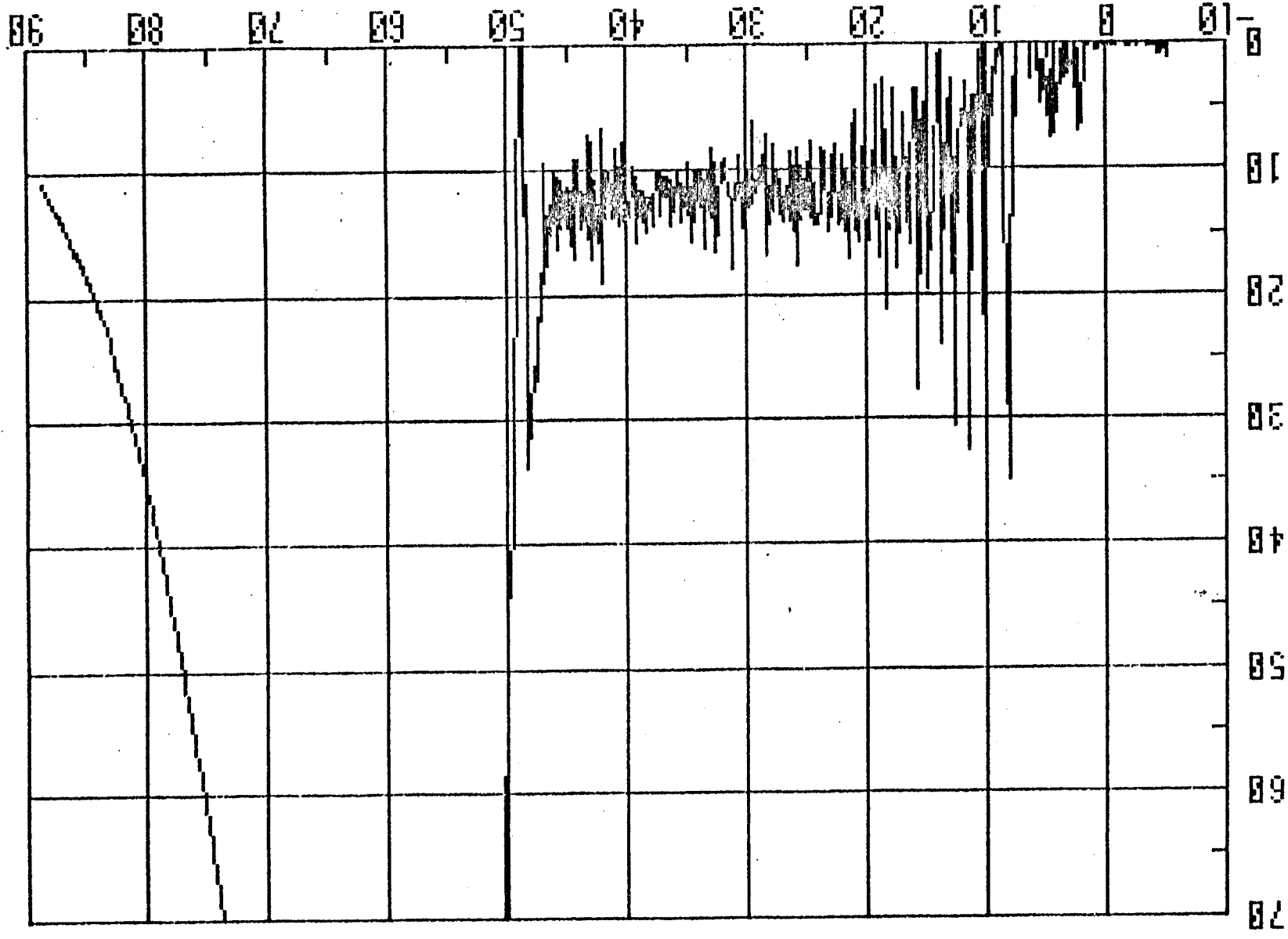


FRT#263: INVRR-36-Stat.: SIC-Rot.

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E-78

Torque Load (Lbf)

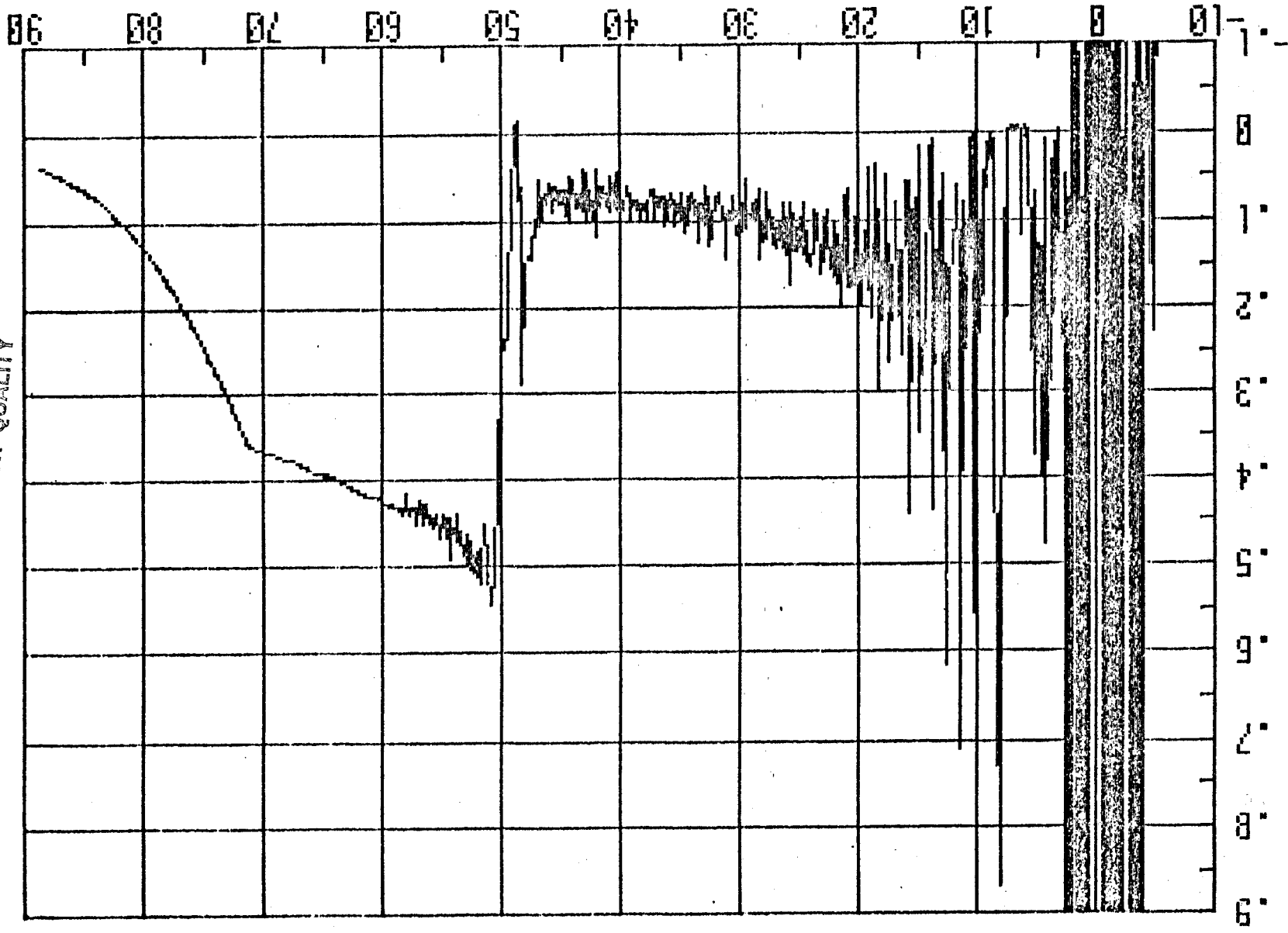


Time (seconds)

FRT#263: INVAR-36-Stat.; SIC-Rot.

Contains a +.5 load offset.

Coefficient of Friction



FRT#263: INVAR-36-Stat.; SIC-Rot.

Time (seconds)

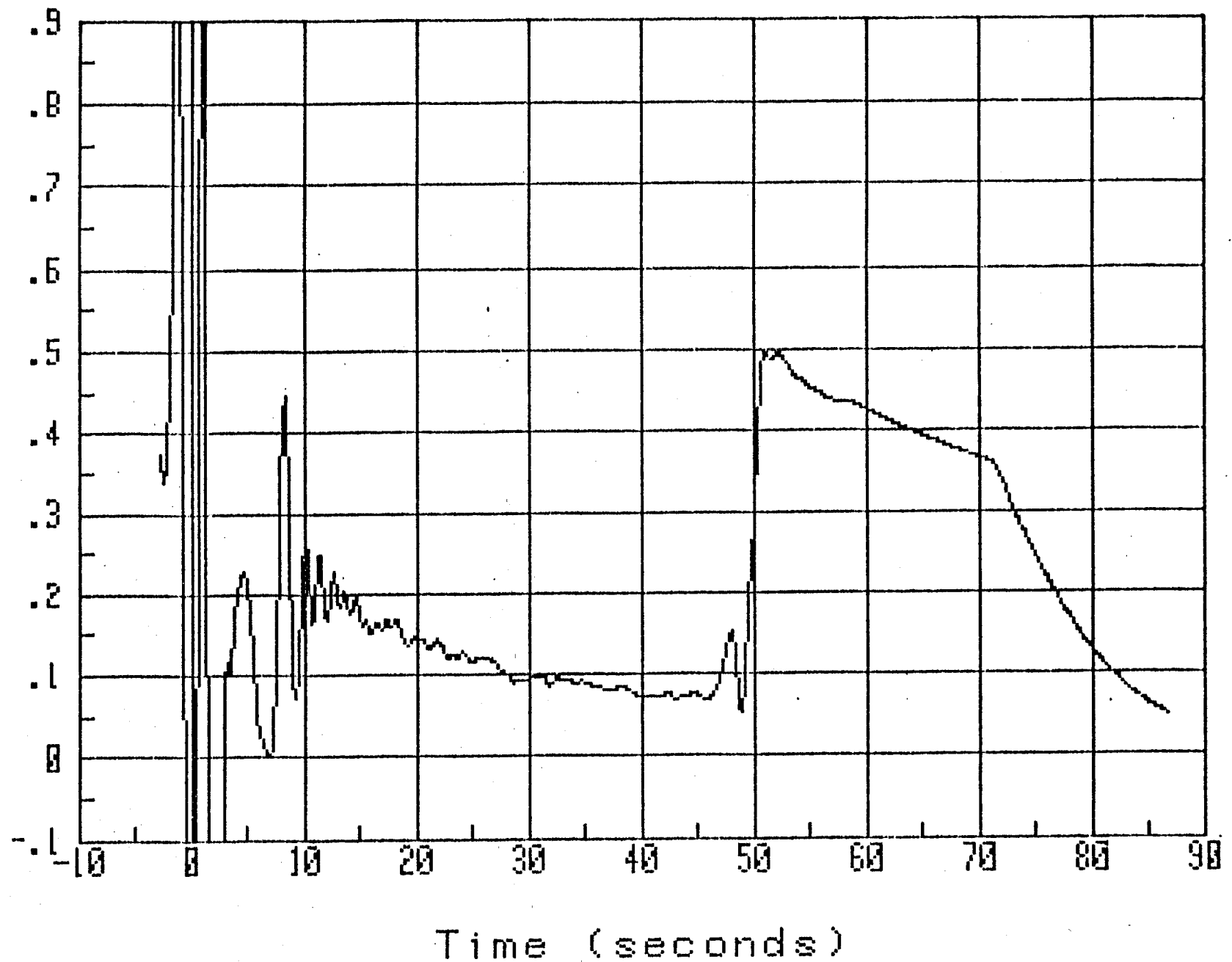
Contains a torque load and a normal load offset.

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FRT#263: INVAR-36-Stat.; SiC-Rot.

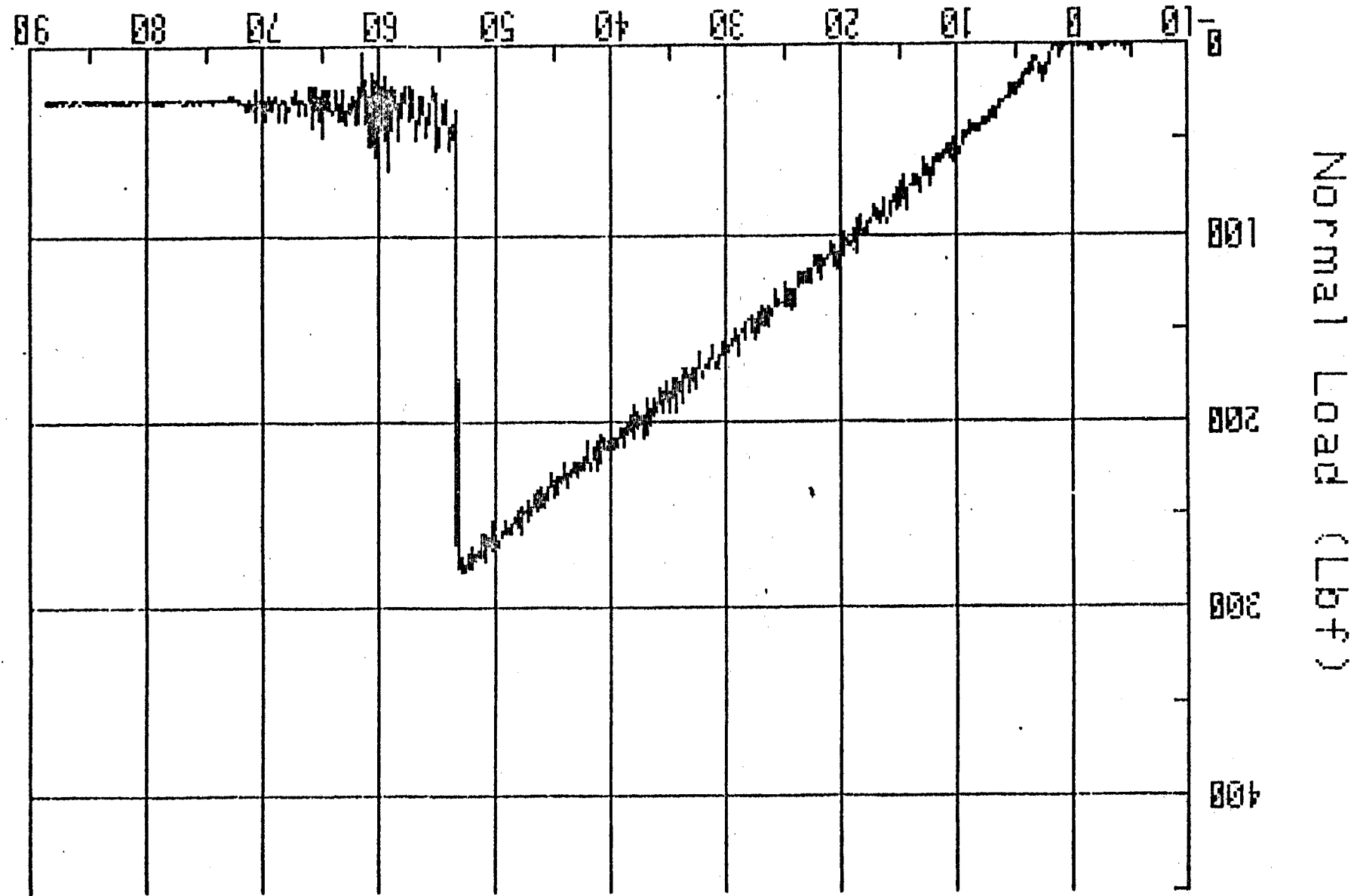
E-80

Filtered Coefficient of Friction



Contains a torque load and a normal load offset.

FRT#264: INVRR-36-Stat.: SIC-Rot.



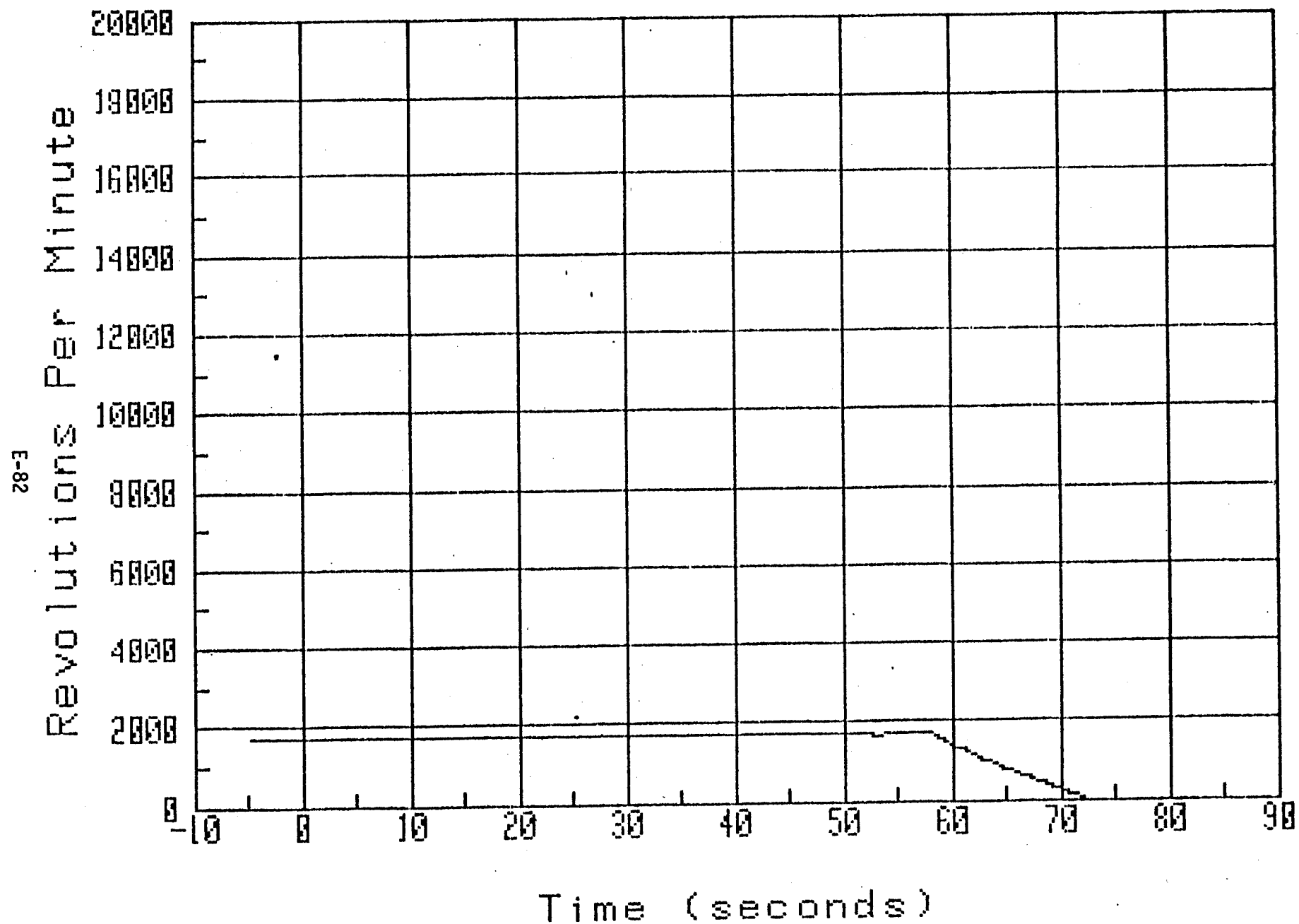
Time (seconds)

Normal Load (Lbf)

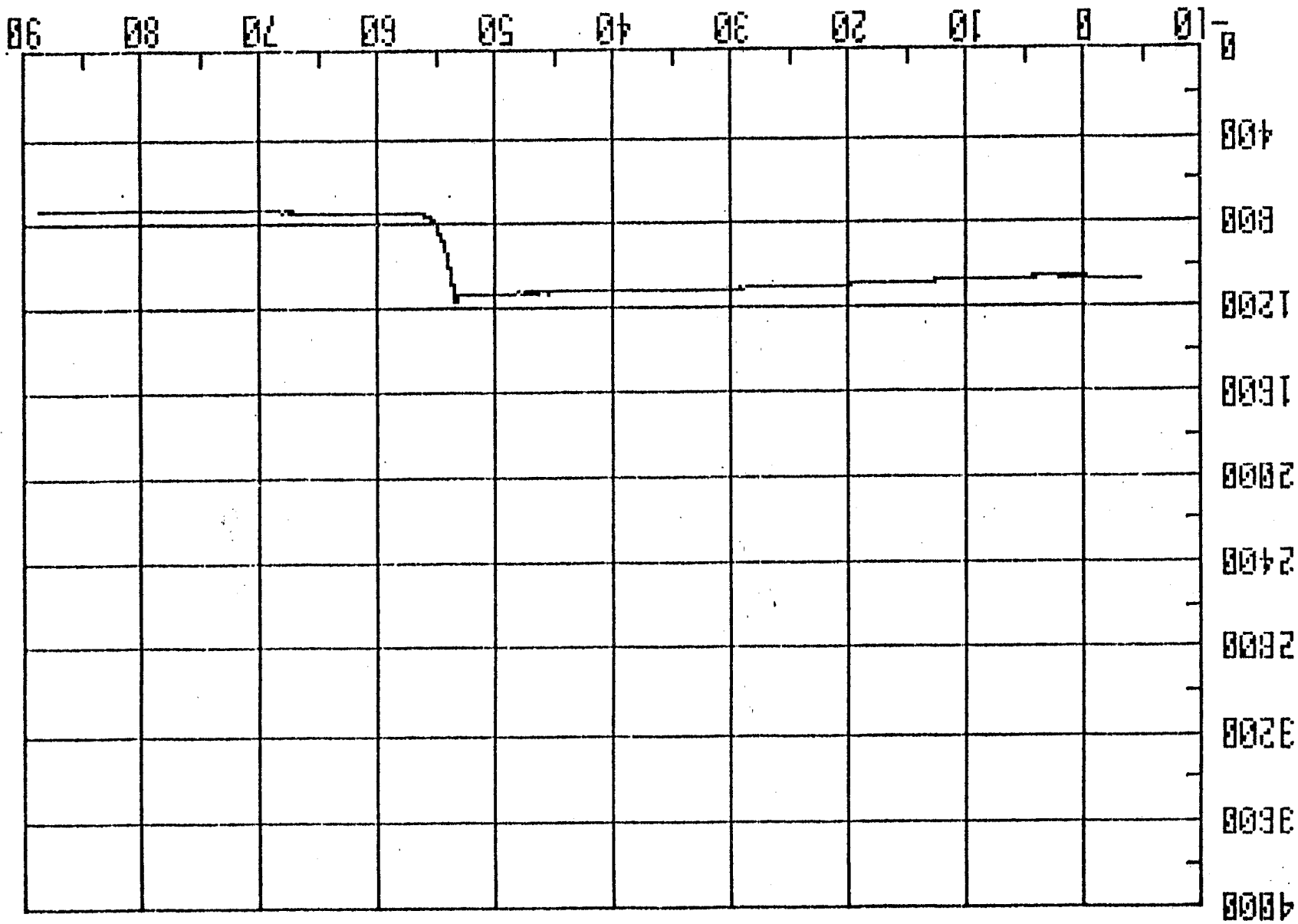
E-81 ORIGINAL PAGE IS OF POOR QUALITY

Continues a -5.4 load offset.

FRT#264: INVAR-36-Stat.; SiC-Rot.

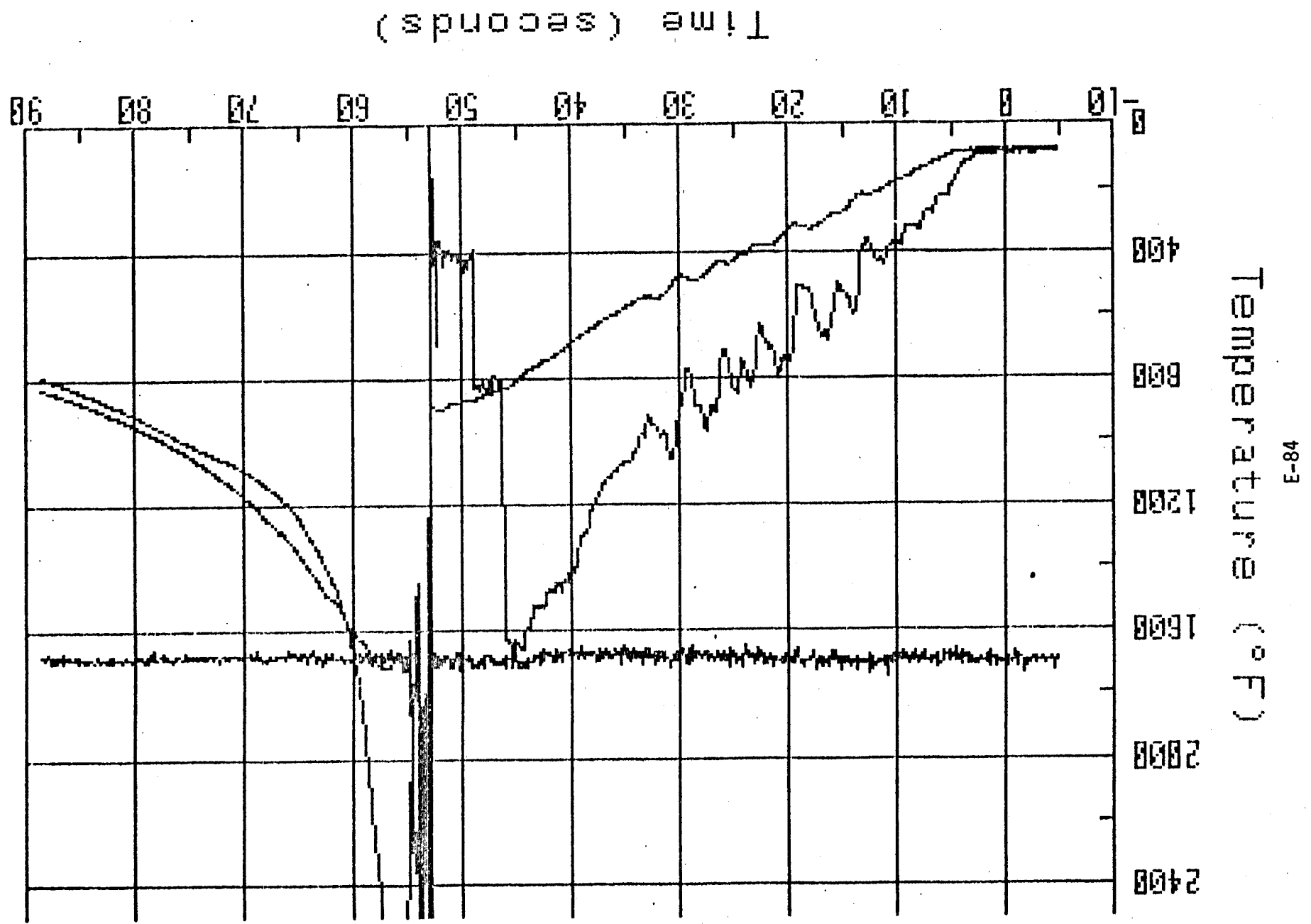


Chamber Oxygen Pressure (PSIG)

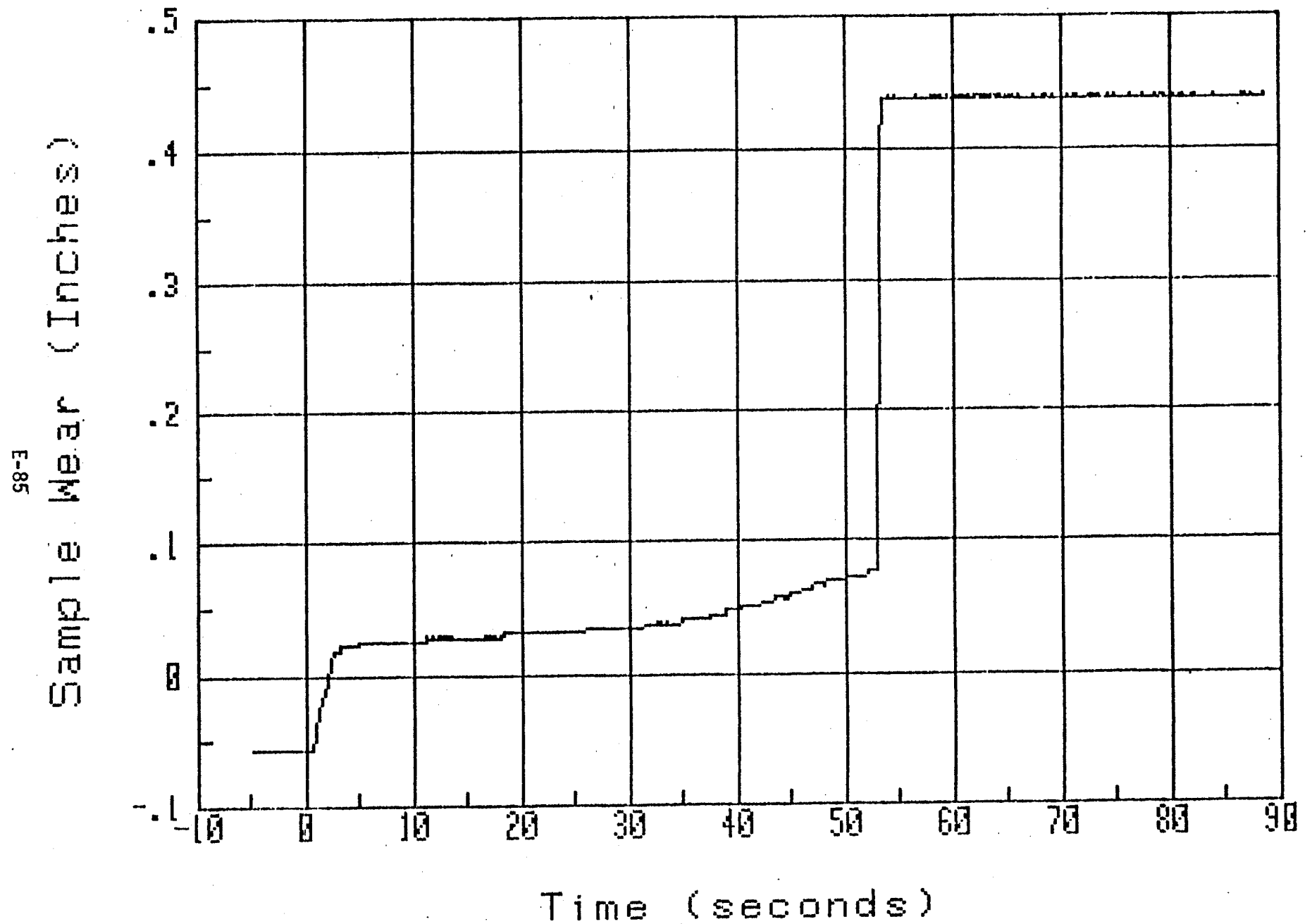


FRT#264: INVRR-36-St at. : SIC-Rot.

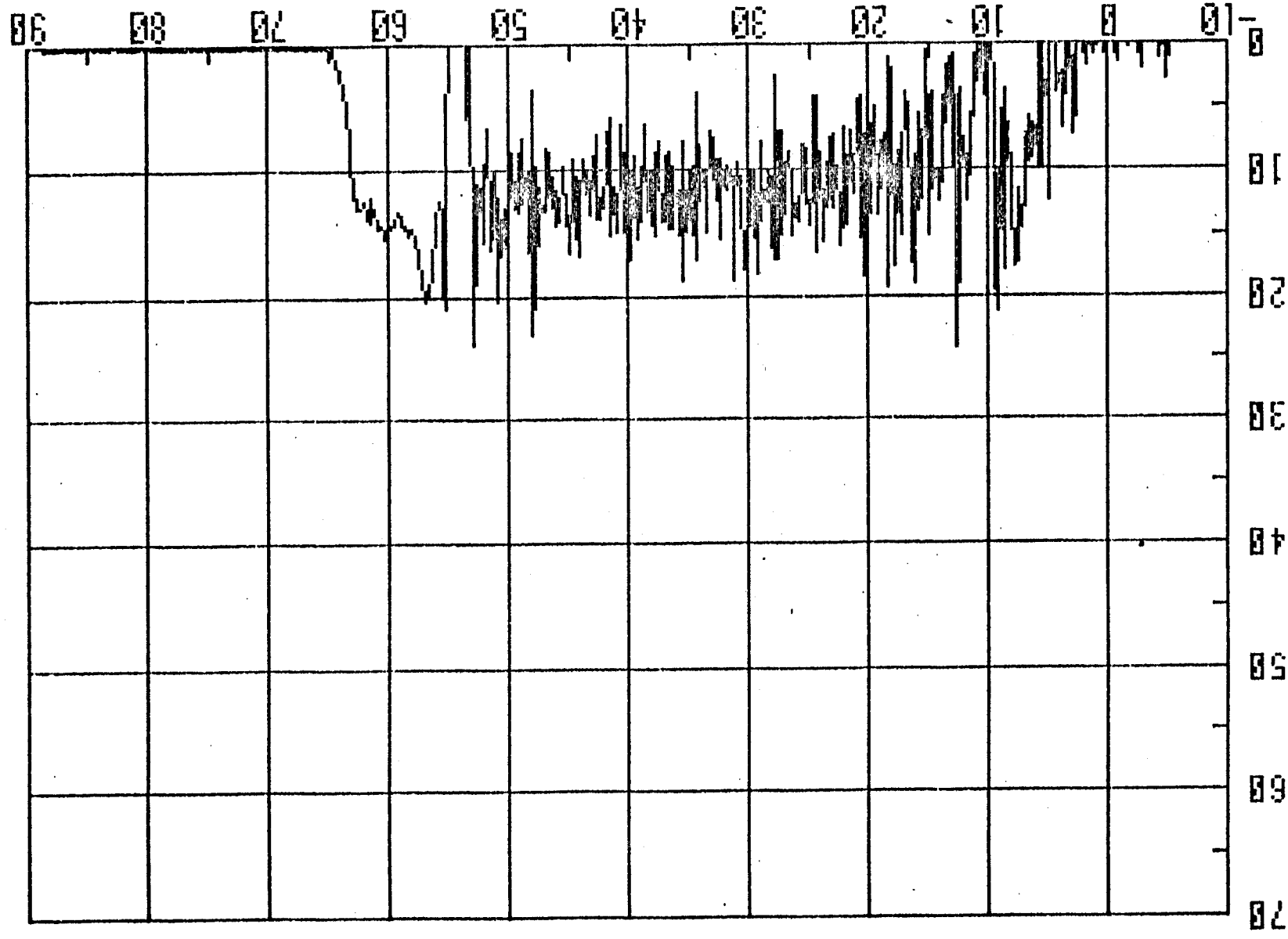
FRT#264: INVR-36-St at. ; SIC-Rot.



FRT#264: INVAR-36-Stat.; SiC-Rot.



FRT#264: INVAR-36-Stat.: SIC-Rot.



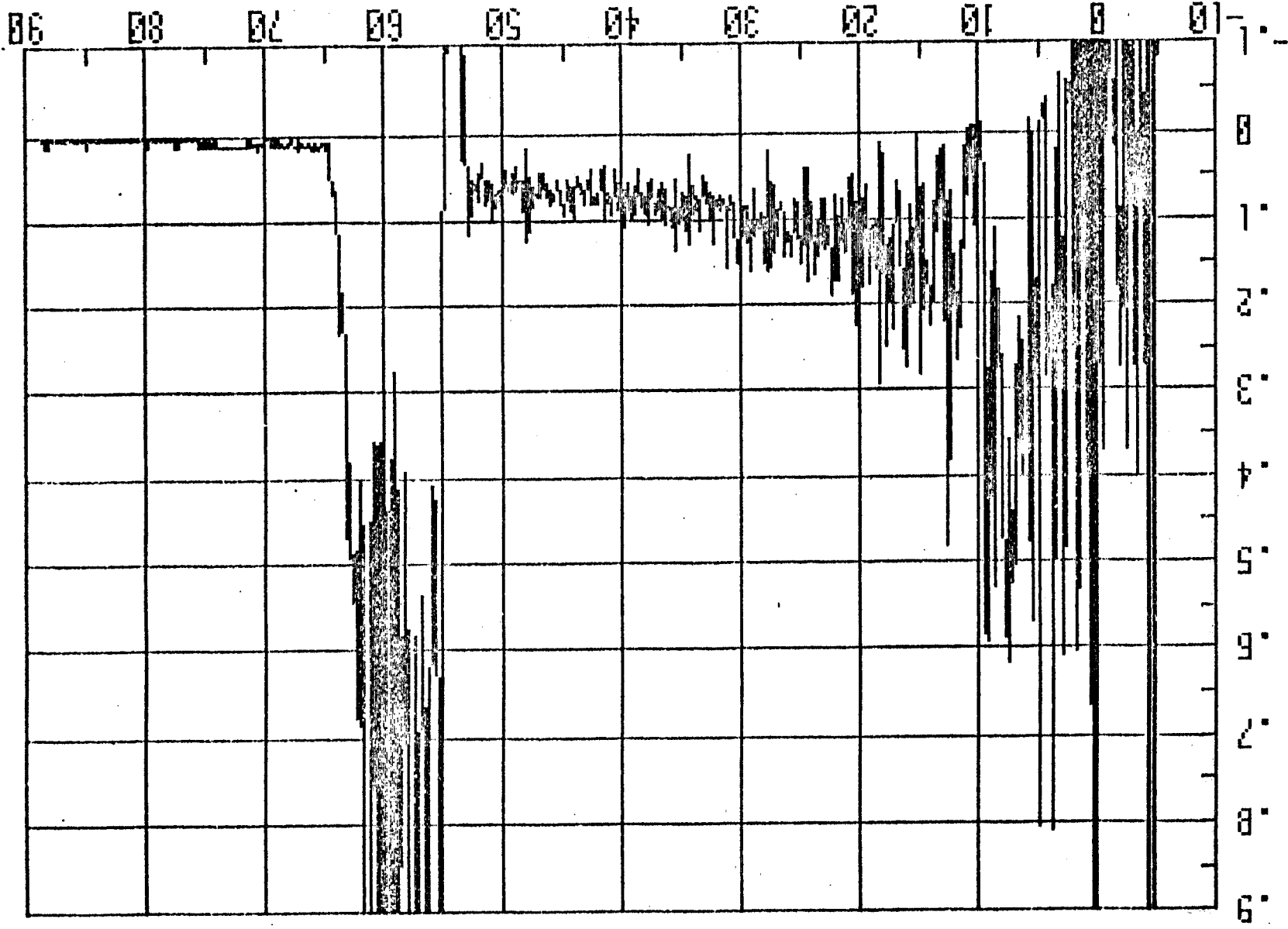
E-86

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Contains a +2.9 load offset.

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FRT#264: INVRR-36-Stat.: SIC-Rot.



Time (seconds)

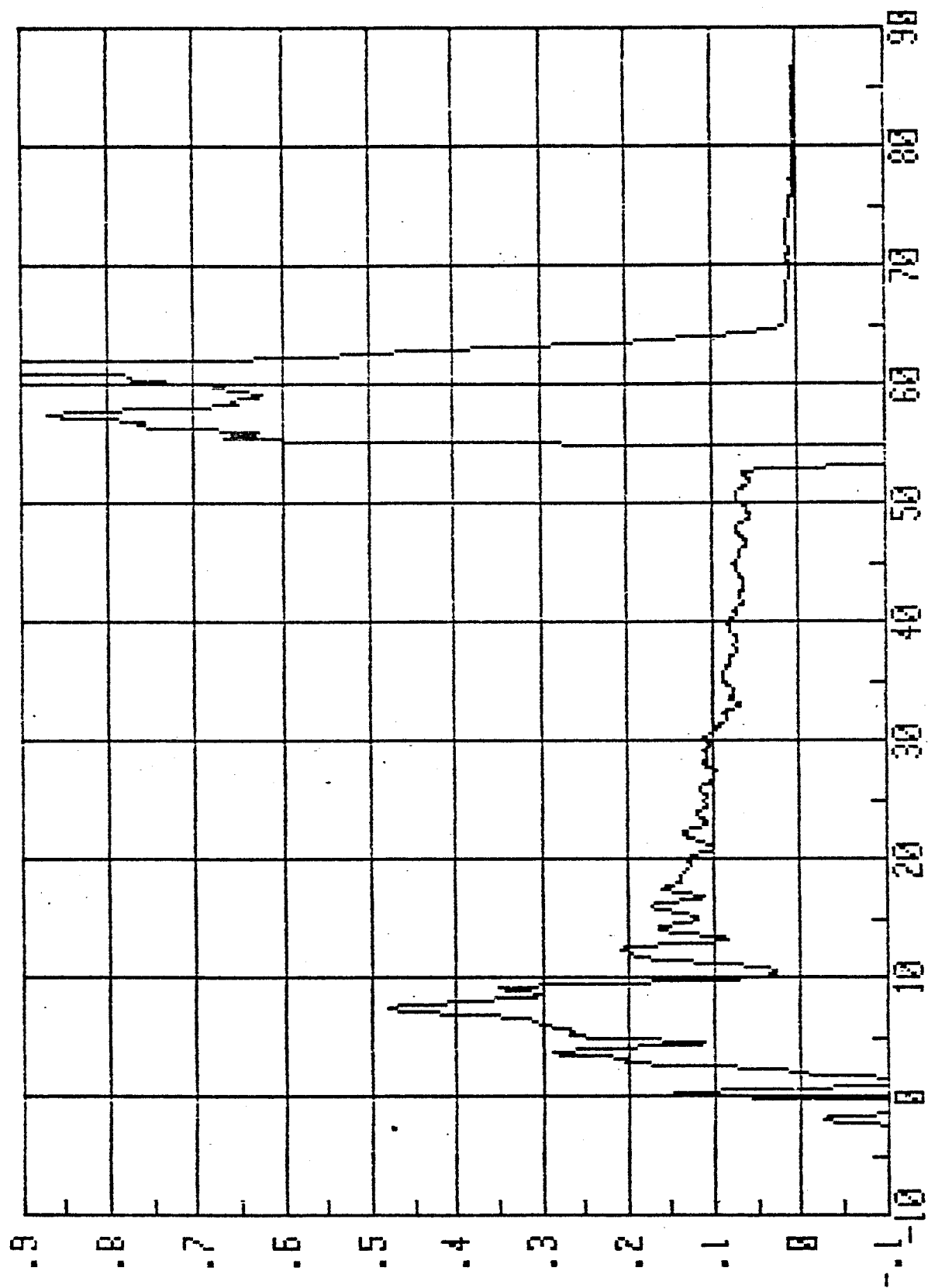
Coefficient of Friction

E-87

Contains a torque load and a normal load offset.

FRT#264: INVAR-36-Stat.; SiC-Rot.

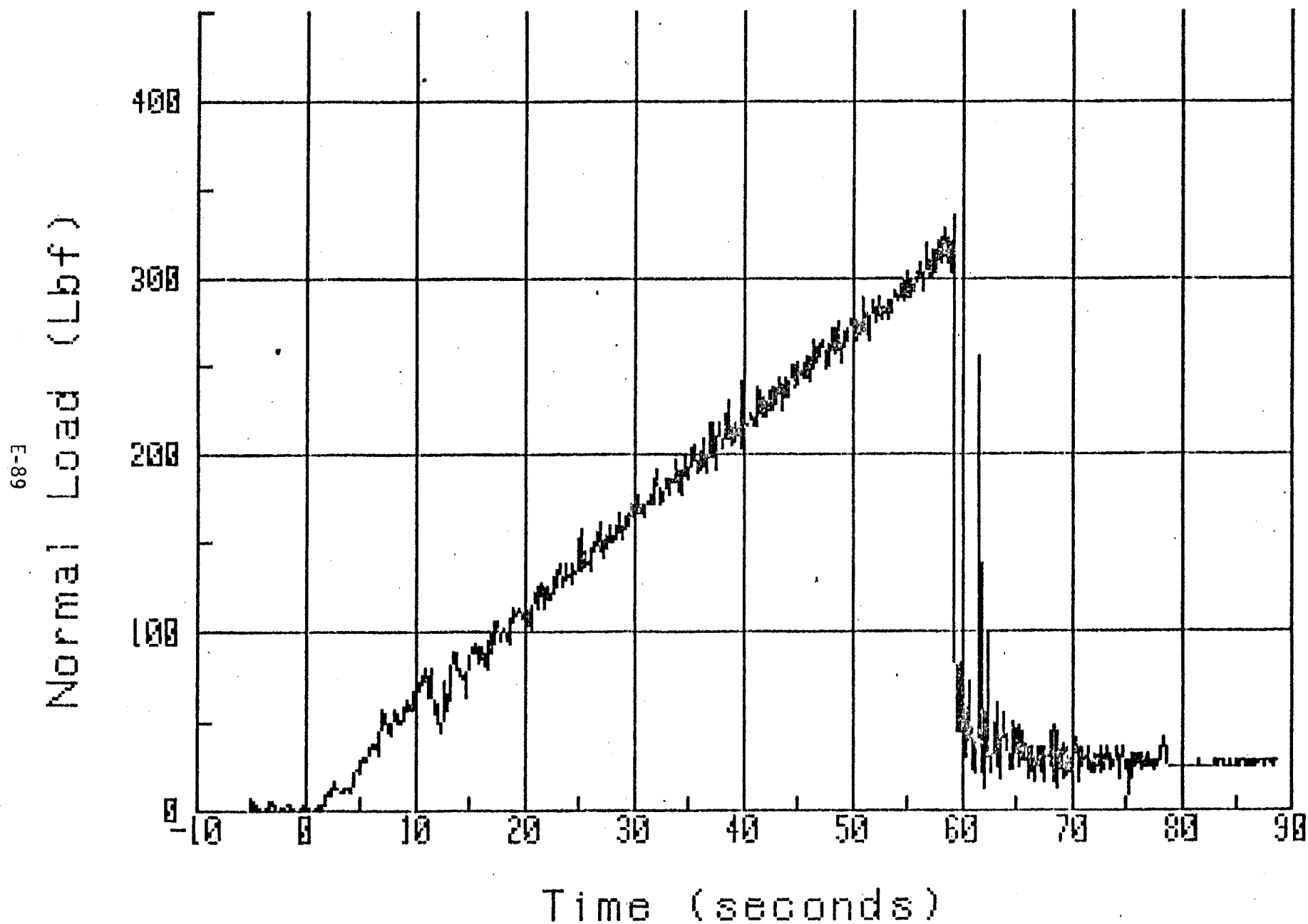
Filtered Coefficient of Friction



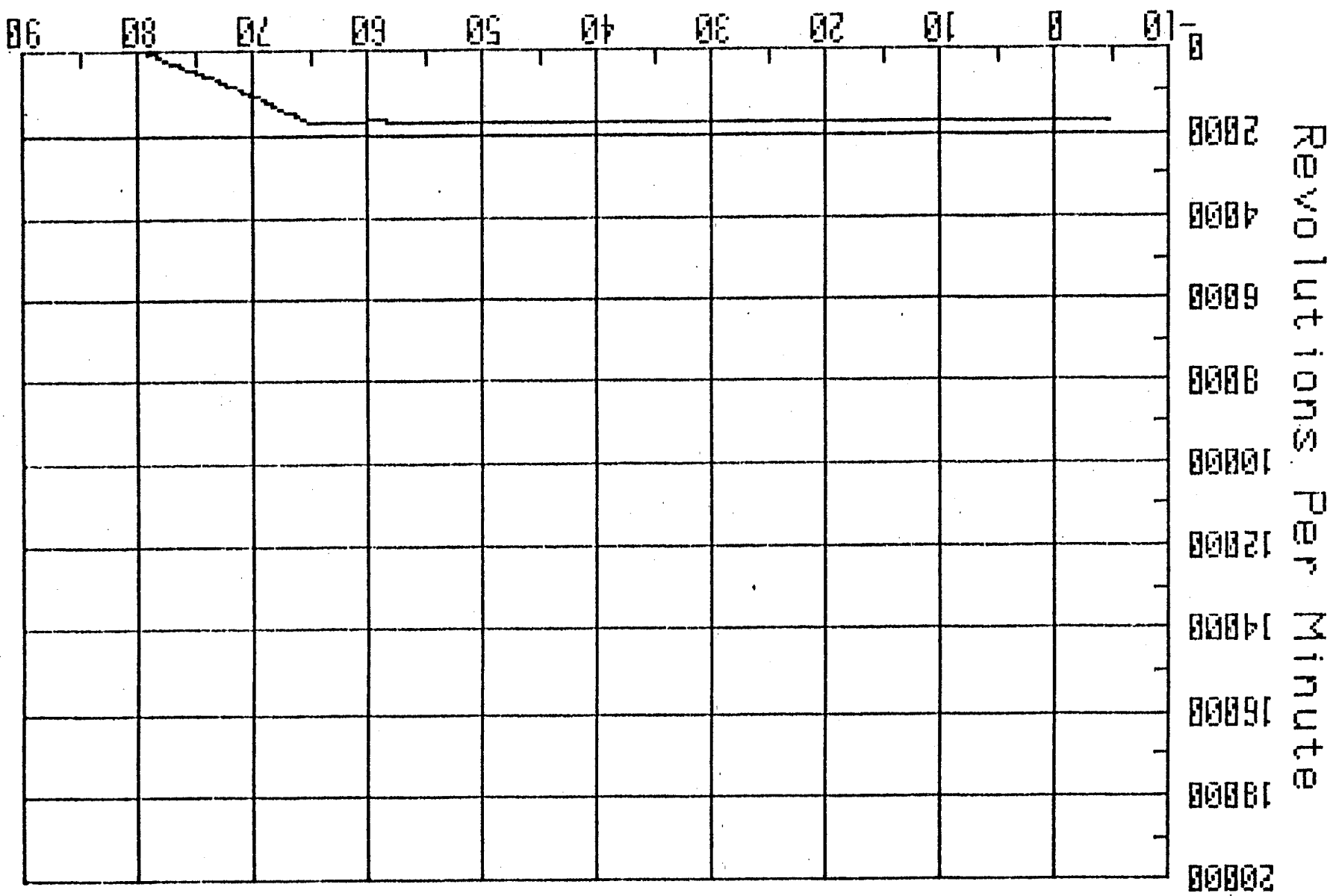
Time (seconds)

Contains a torque load and a normal load offset.

FRT#265: INVAR-36-Stat.; SiC-Rot.



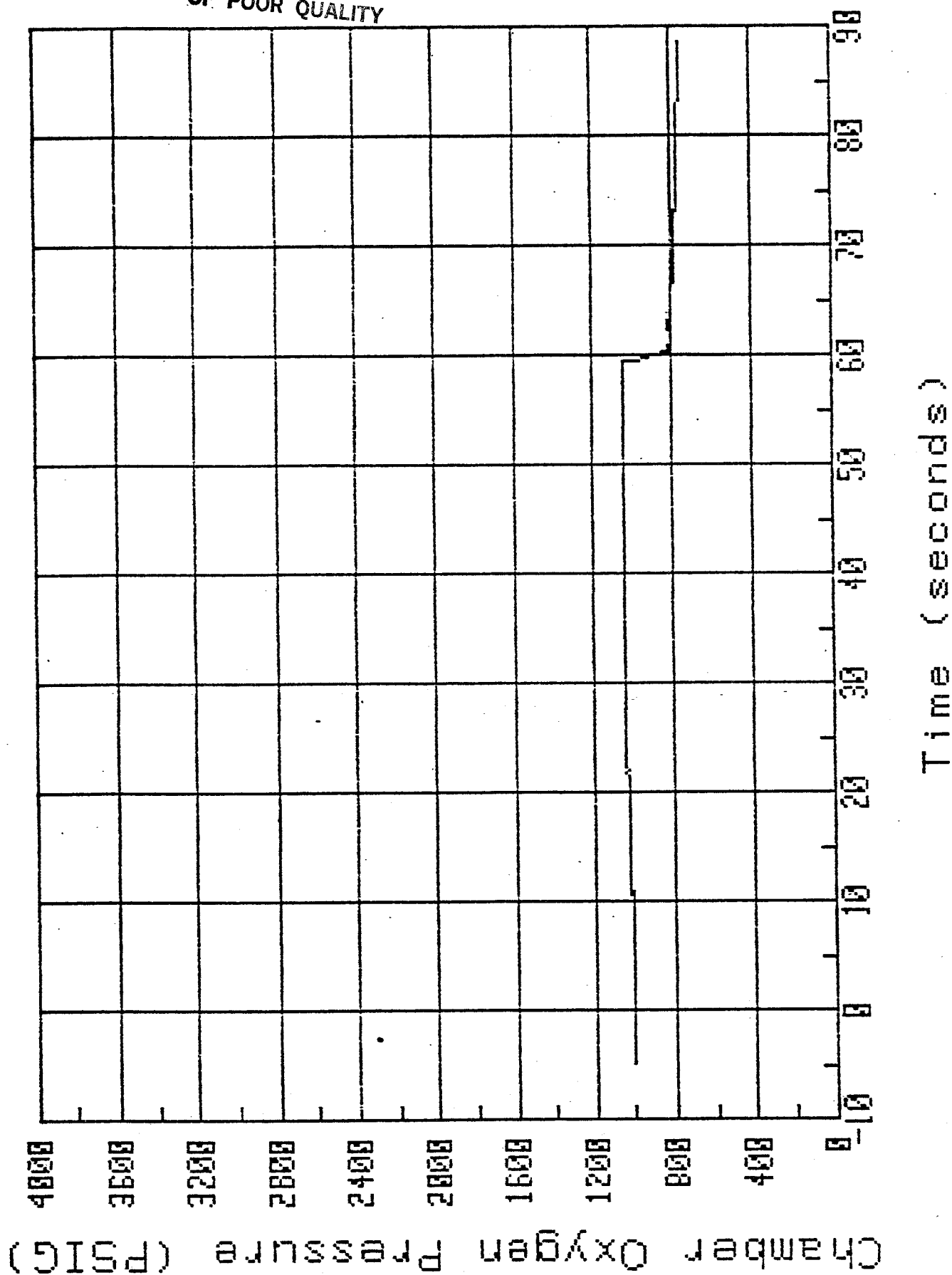
Contains a -10.7 load offset.



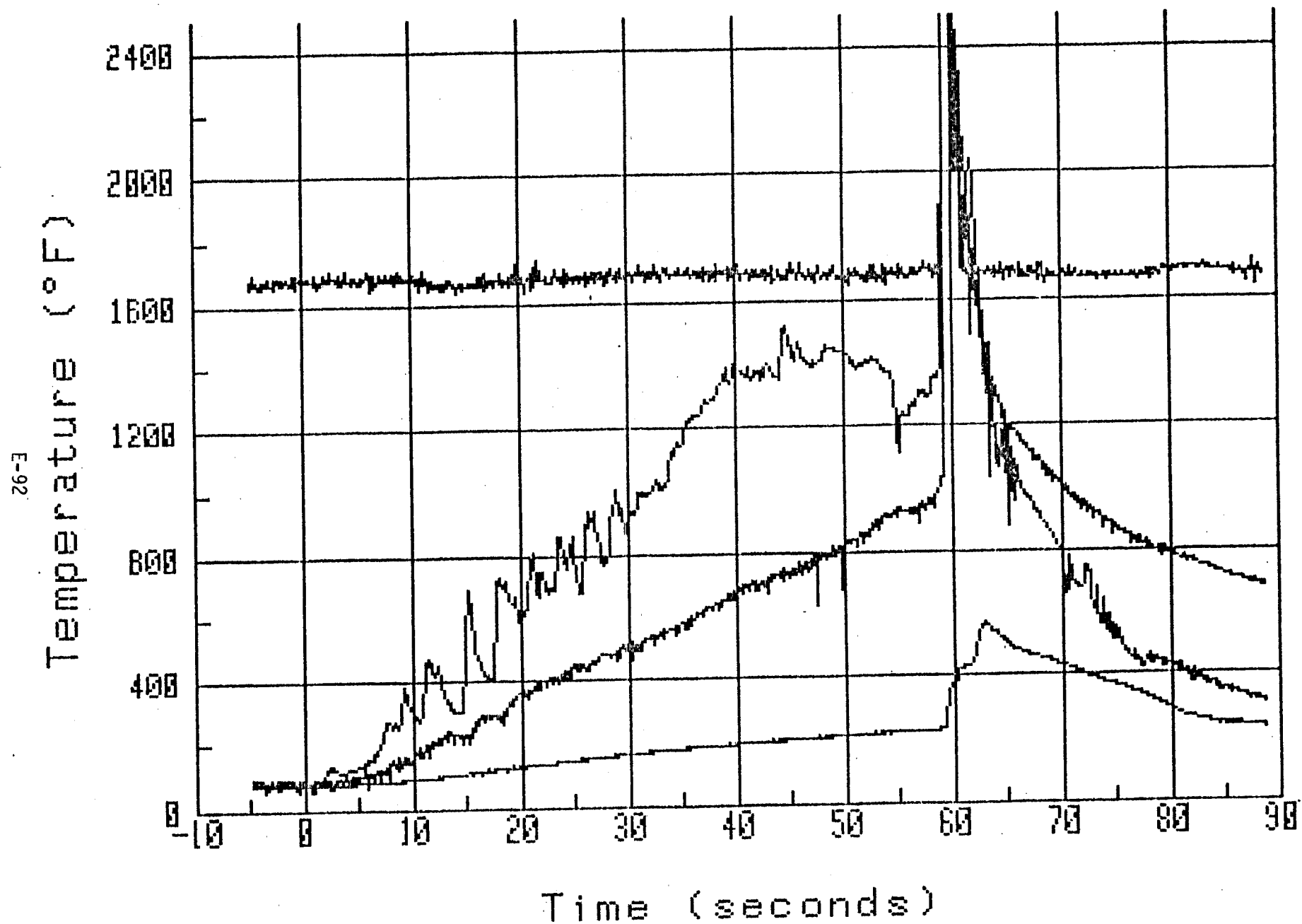
FRT#265: INVR-36-St at. ; SIC-Rot.

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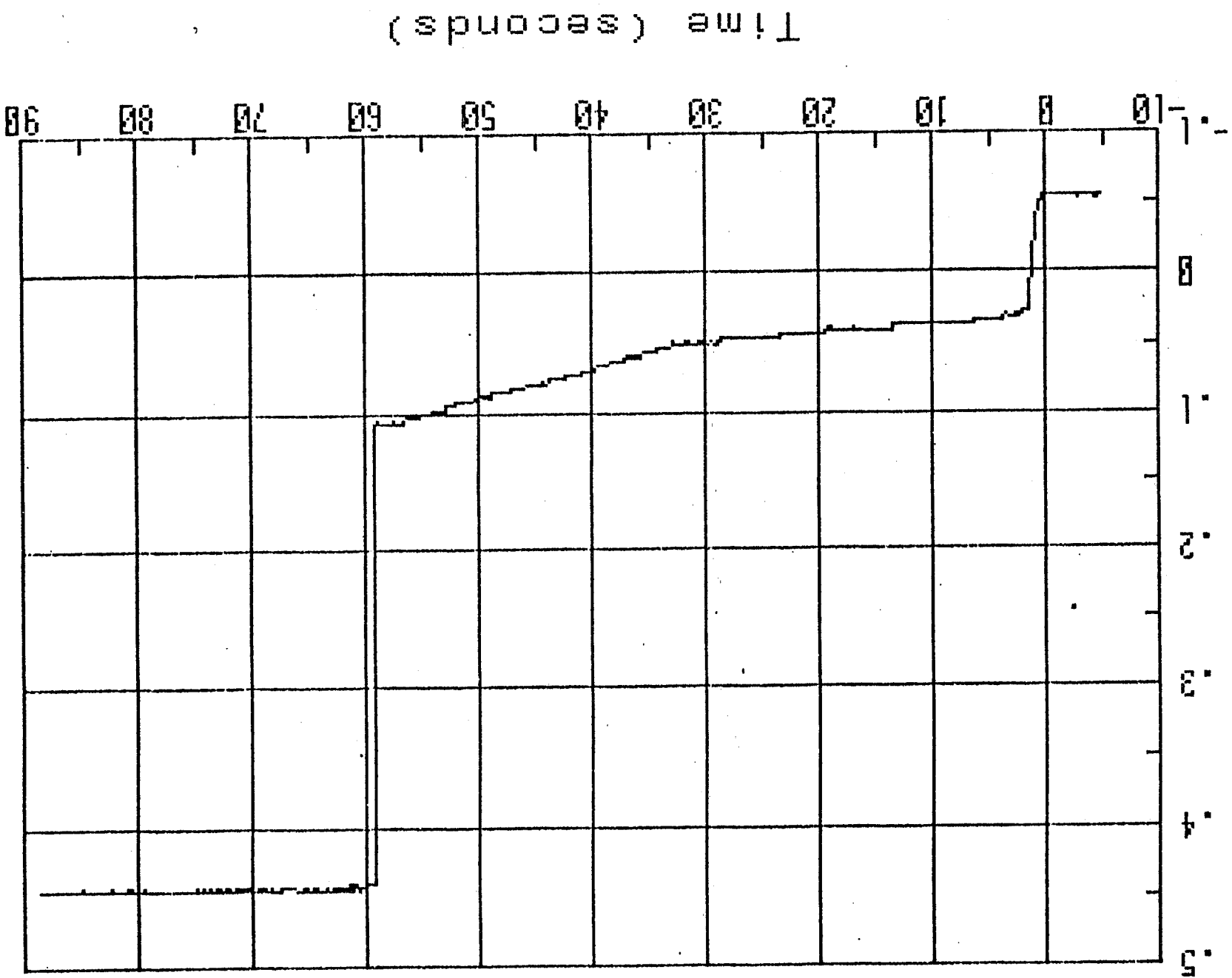
FRT#265: INVAR-36-Stat.; SiC-Rot.



FRT#265: INVAR-36-Stat.; SiC-Rot.



Sample Wear (Inches)



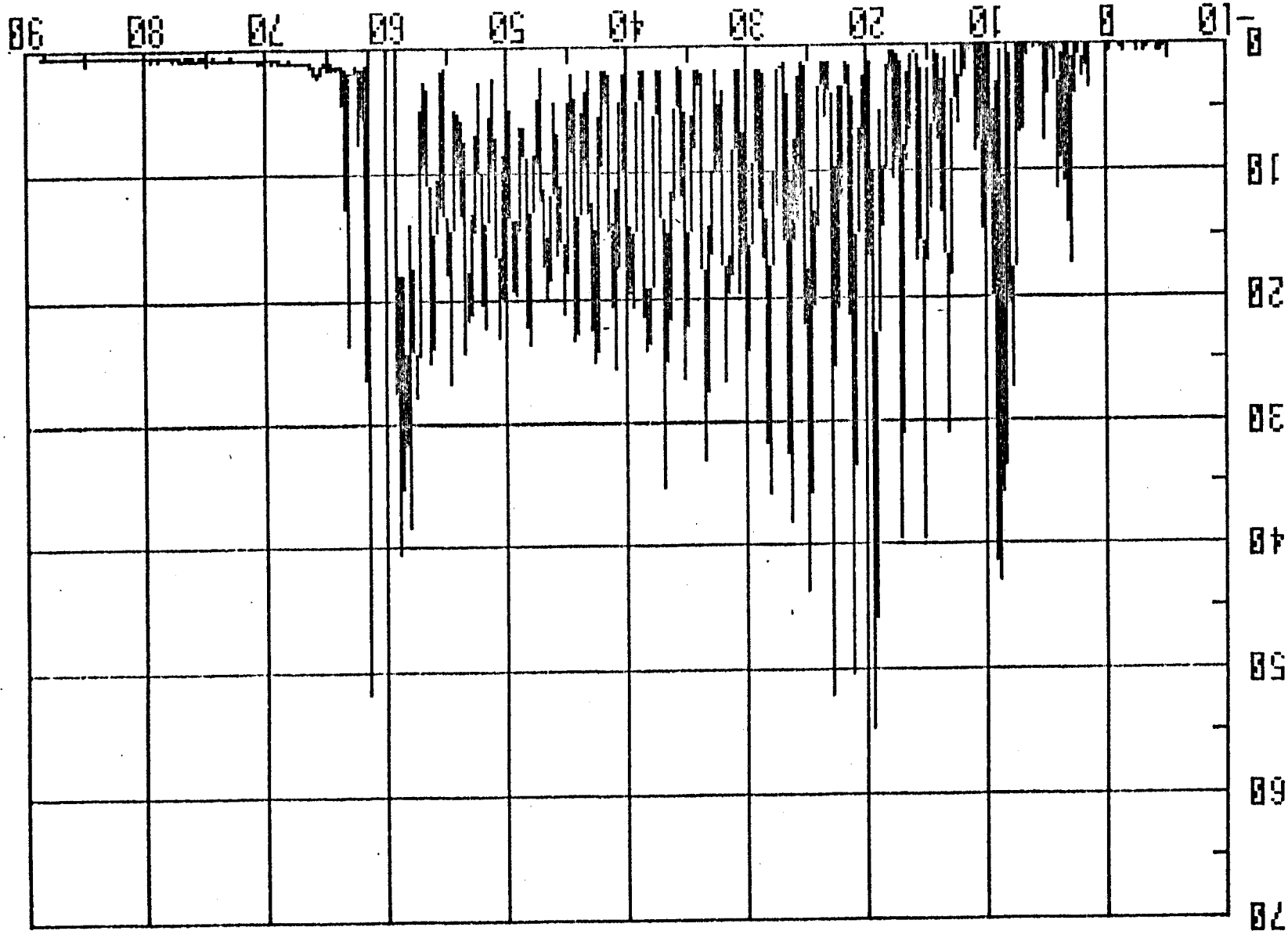
FRT#265: INVAR-36-St at. : SIC-Rot.

FRT#265: INVRR-36-Stat.; SIC-Rot.

Torque Load (Lbf)

E-94

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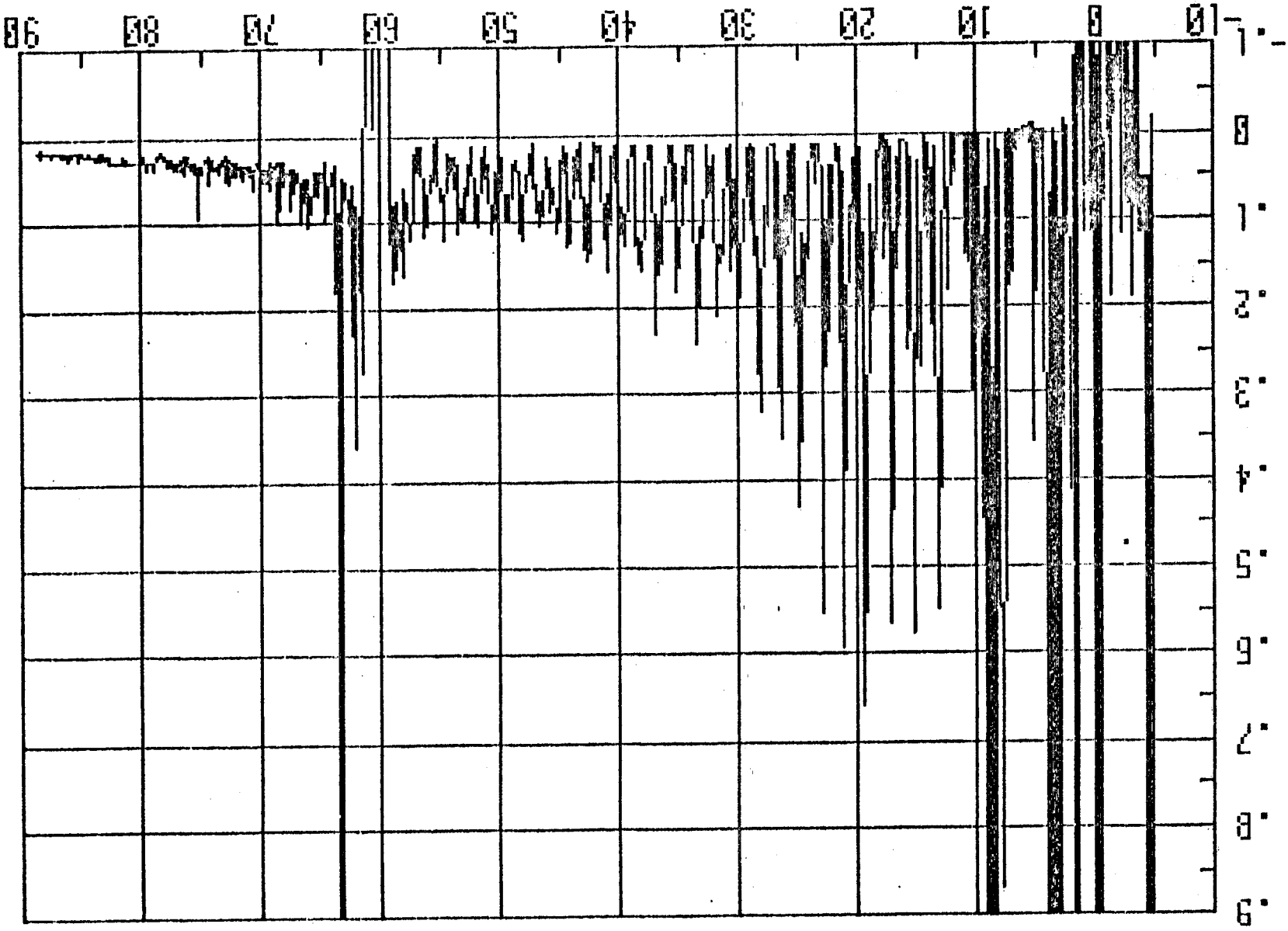
Time (seconds)

Contains a +1.5 load offset.

Coefficient of Friction

Time (seconds)

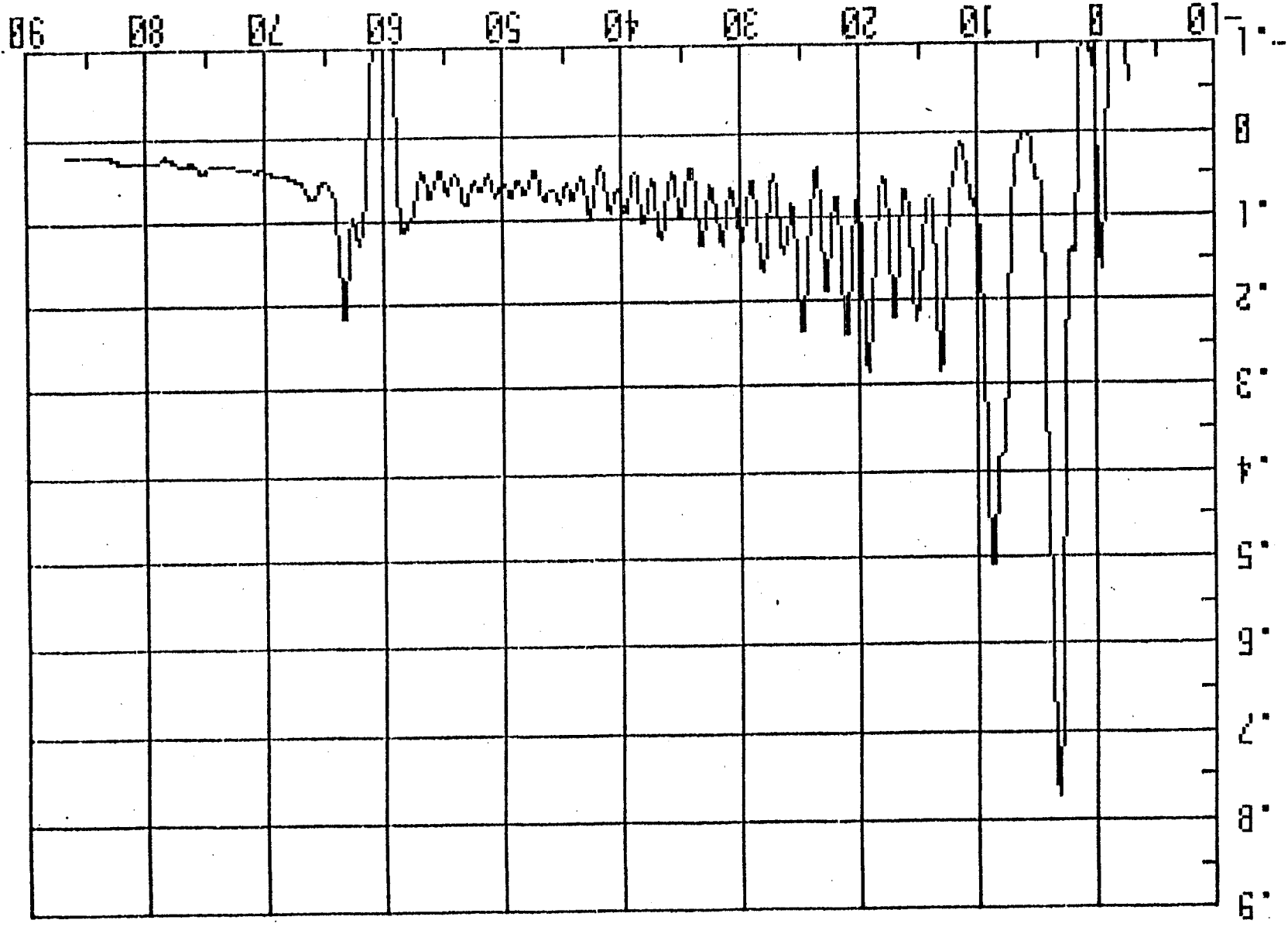
Constant torque load and a normal load offset.



FRT#265: INVAR-36-Stat.: SIC-Rot.

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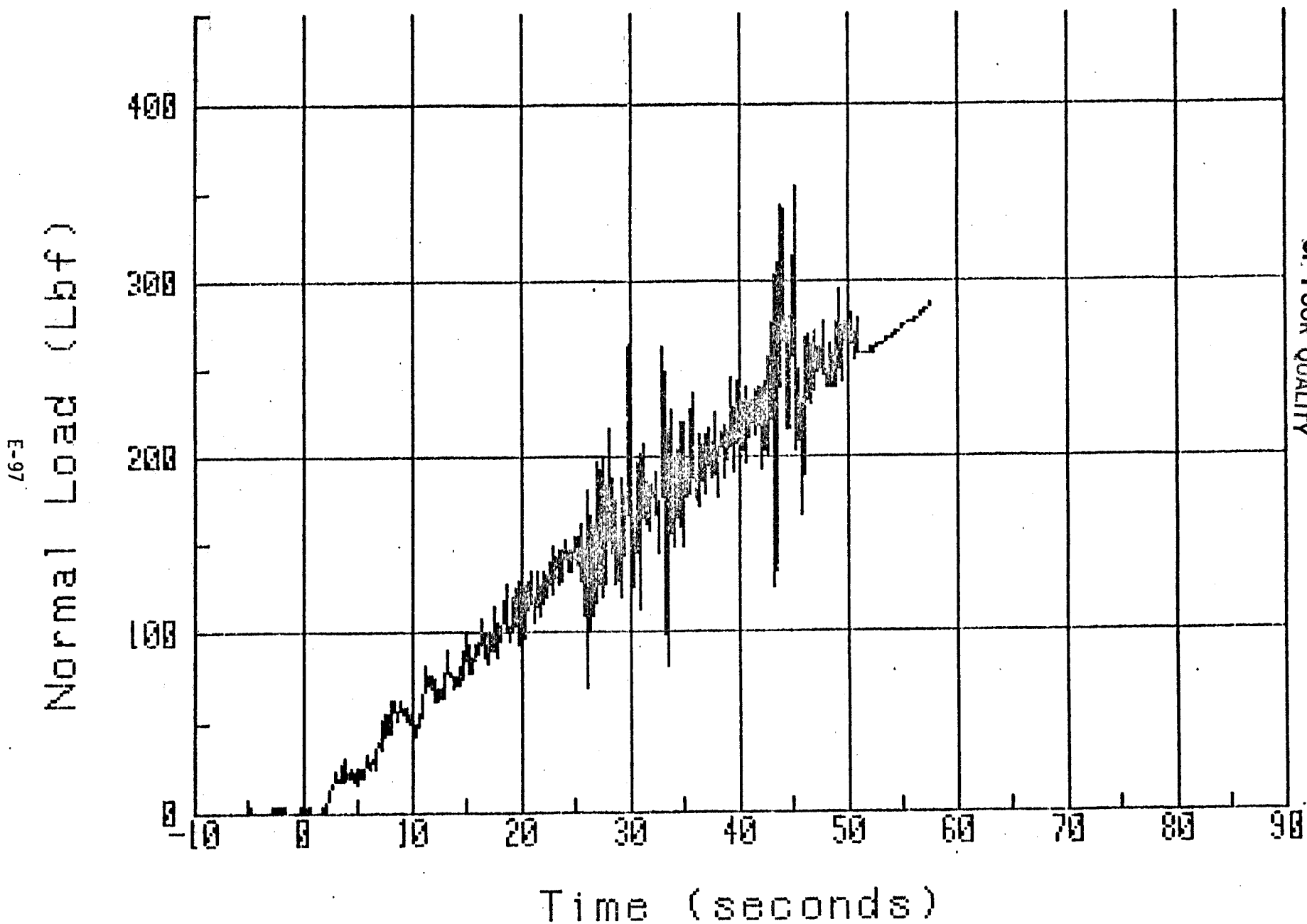
Filtered Coefficient of Friction



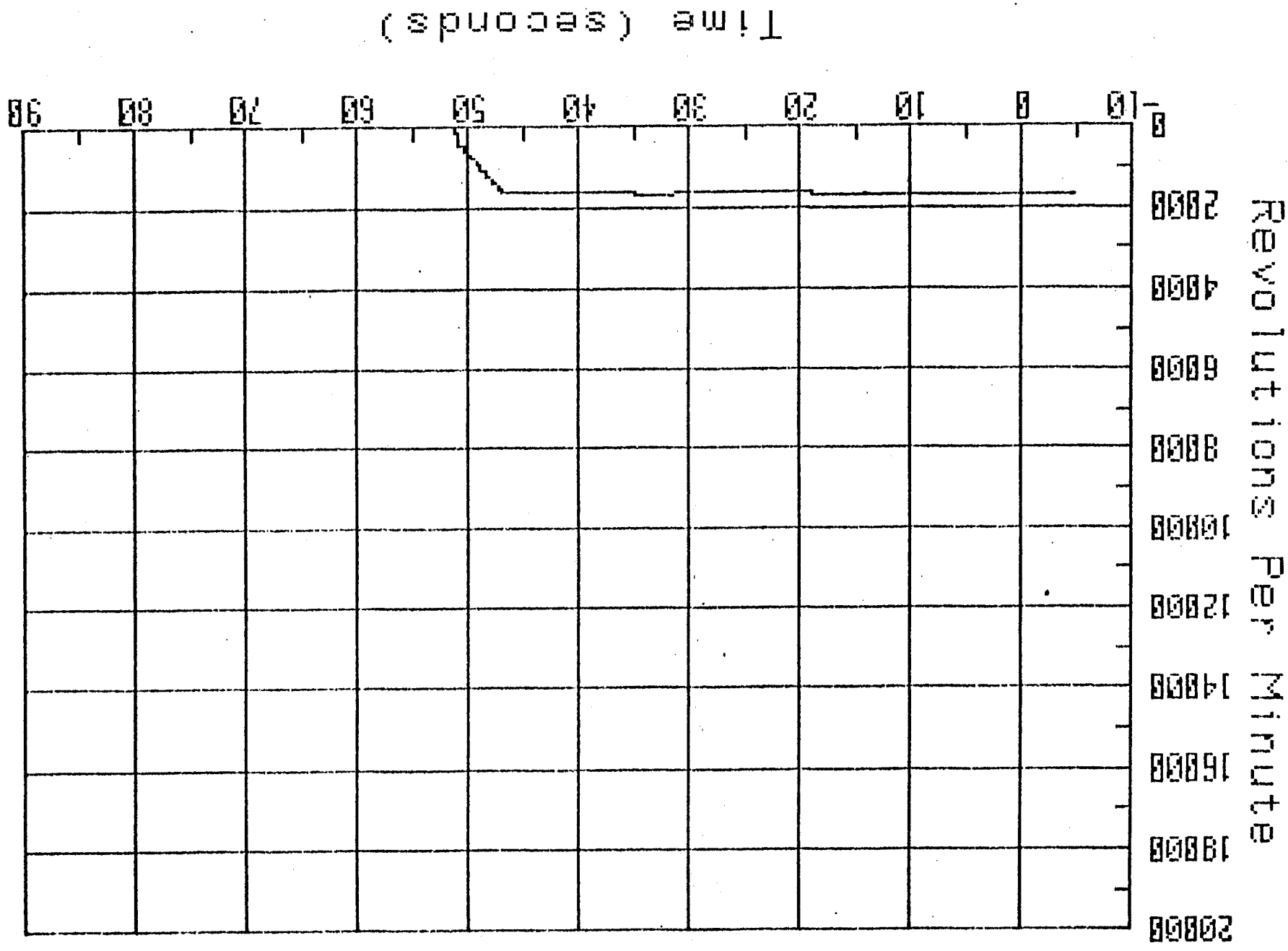
FRT#265: INVAR-36-Stat.; SIC-Rot.

Contains a torque load and a normal load offset.

FRT#266: Mon. K500-Stat.; SiC-Rot.

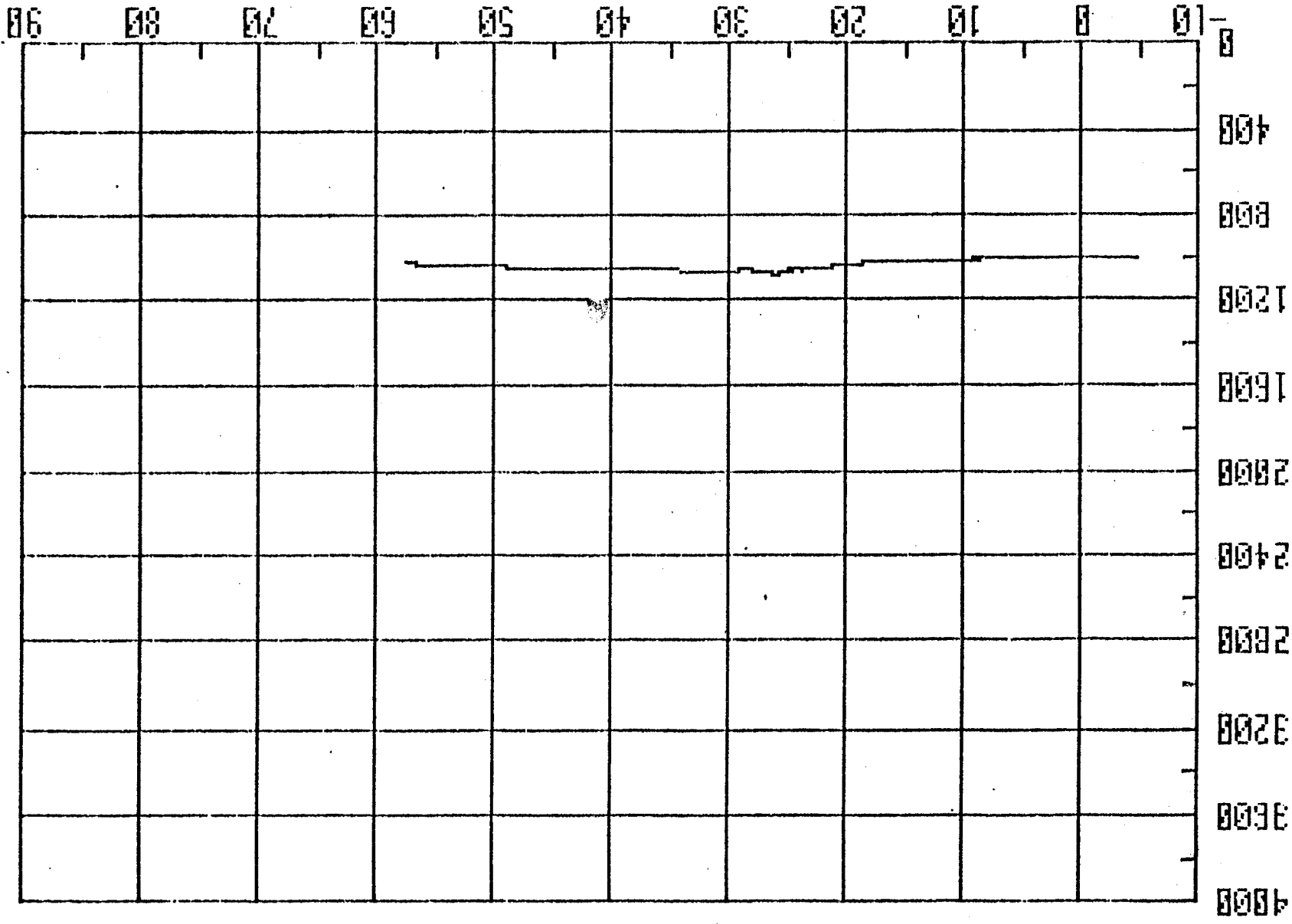


E-98



FRT#266 : Mon. K500-Stat. : SIC-Rot.

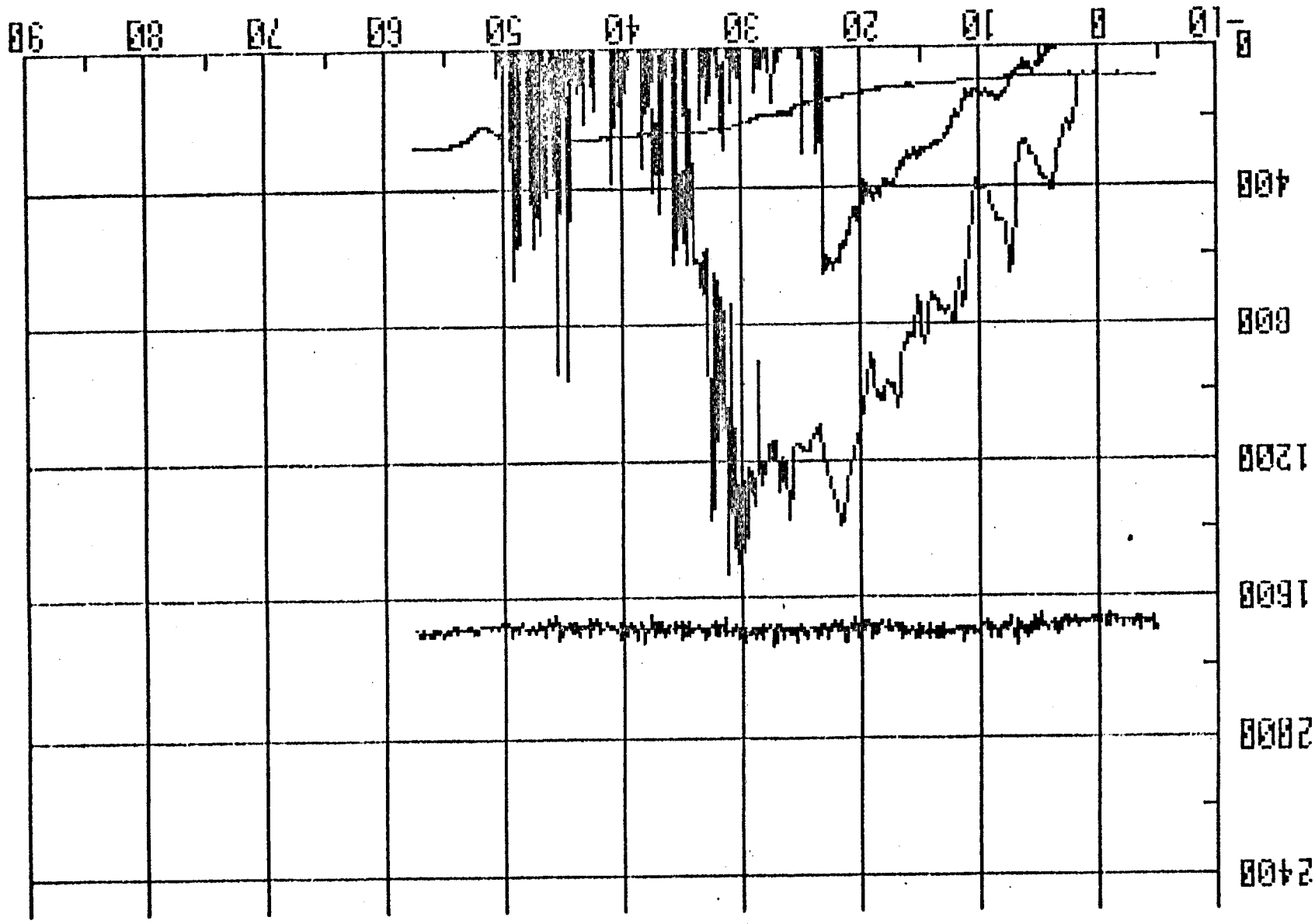
Chamber Oxygen Pressure (PSIG)



FRT#266: Mon. K500-Stat.: SIC-Rot.

001-3

Temperature (°F)

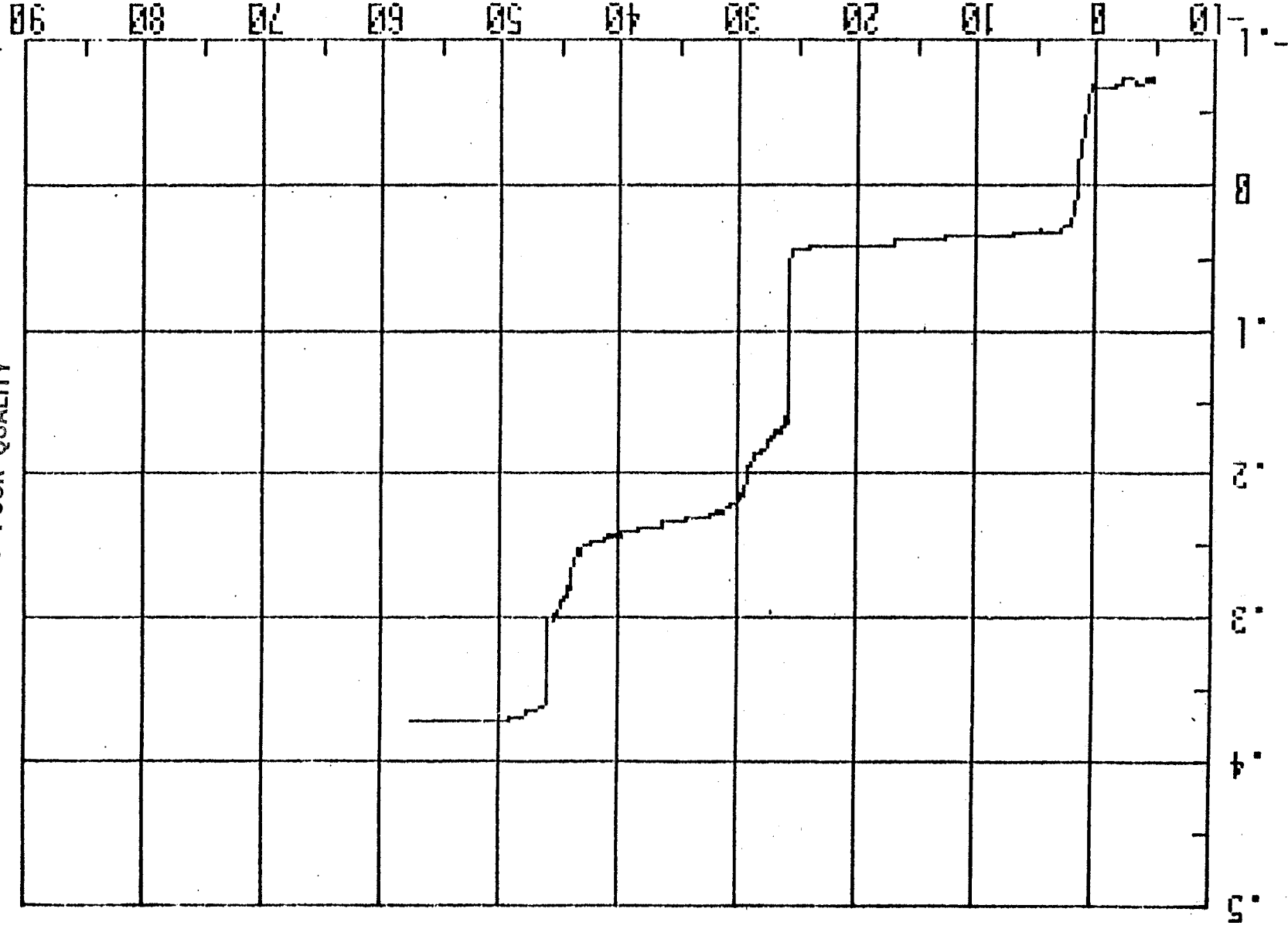


Time (seconds)

FRT#266: Mon. K500-Stat.: SIC-Rot.

Sample Wear (Inches) E-101

Time (seconds)

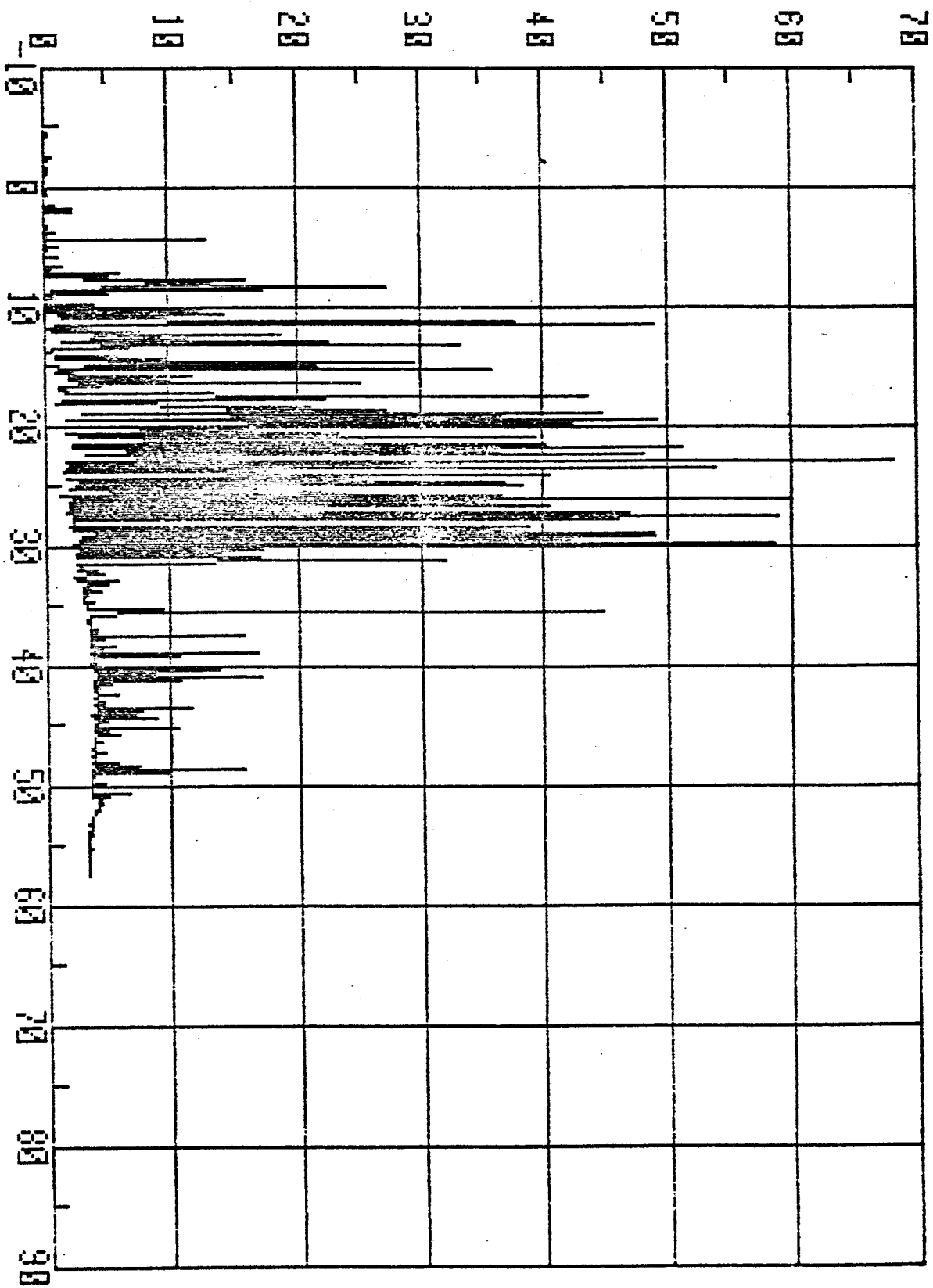


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FRT#266: Mon. K500-Stat.: SIC-Rot.

FRT#266: Mon. K500-Stat.; Sic-Rot.

Torque Load (Lbf)



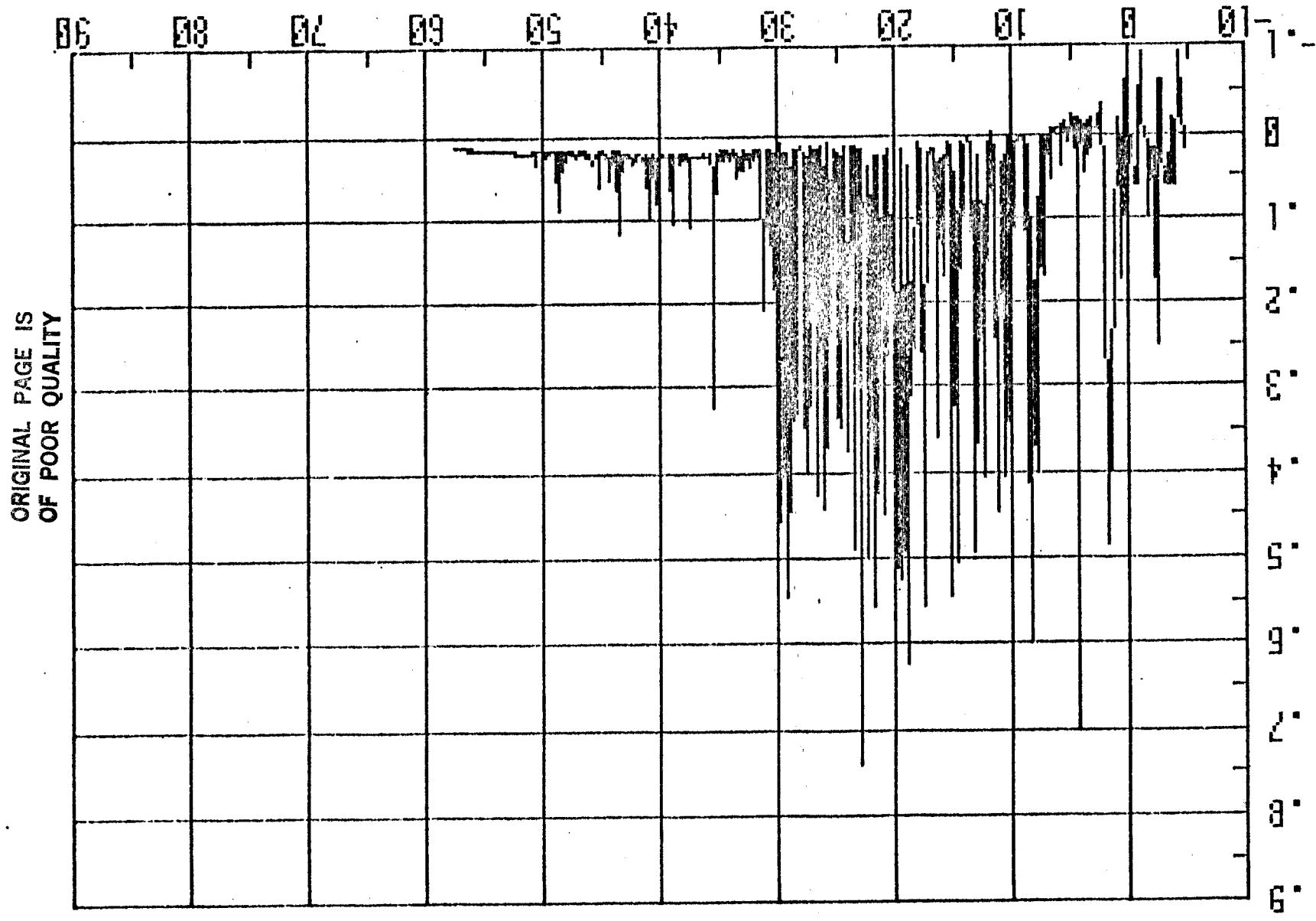
E-102

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Time (seconds)

Contains a +3.6 load offset.

Coefficient of Friction



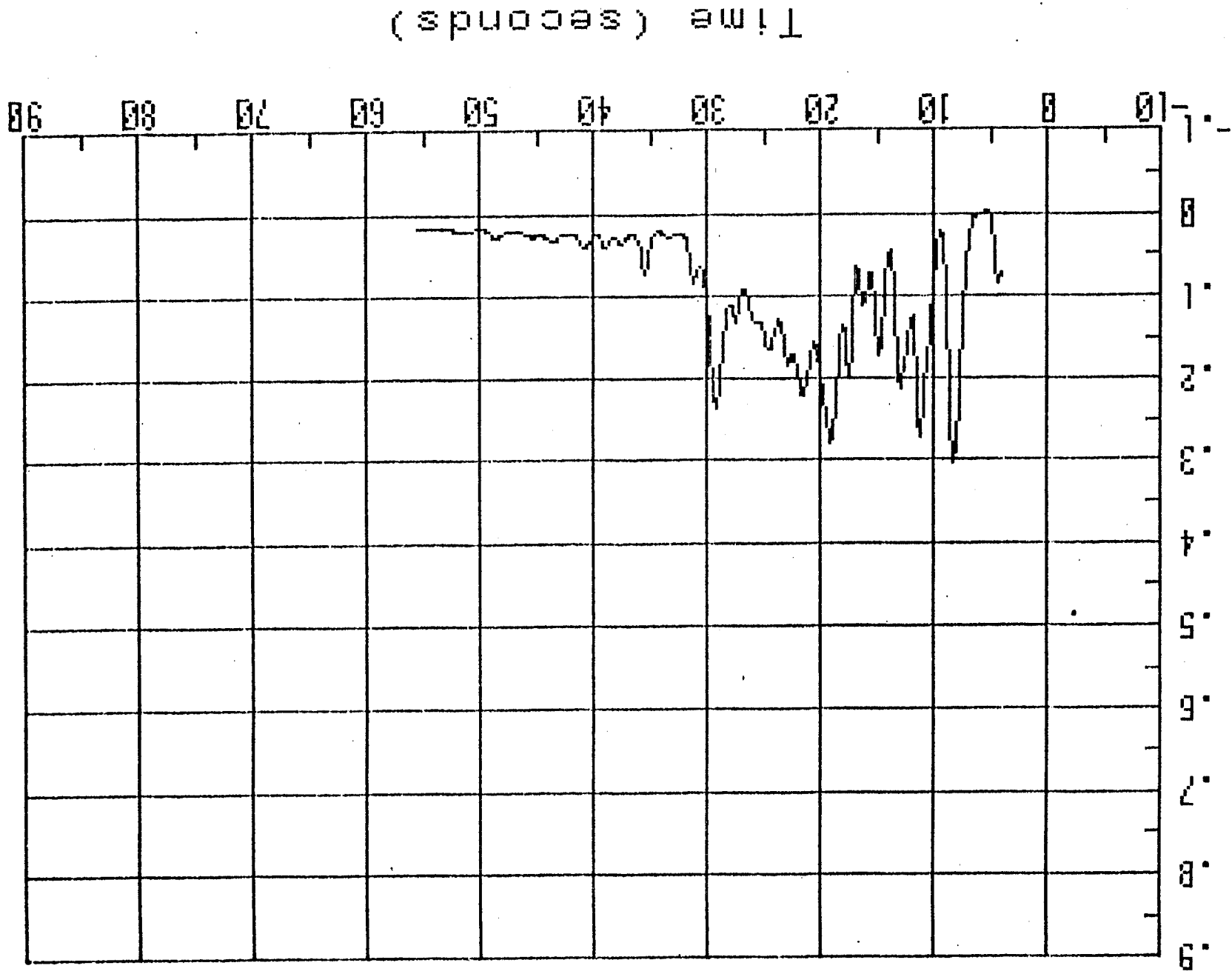
Time (seconds)

Contains a torque load and a normal load offset.

FRT#266 : Mon. K500-Stat. : SIC-Rot.

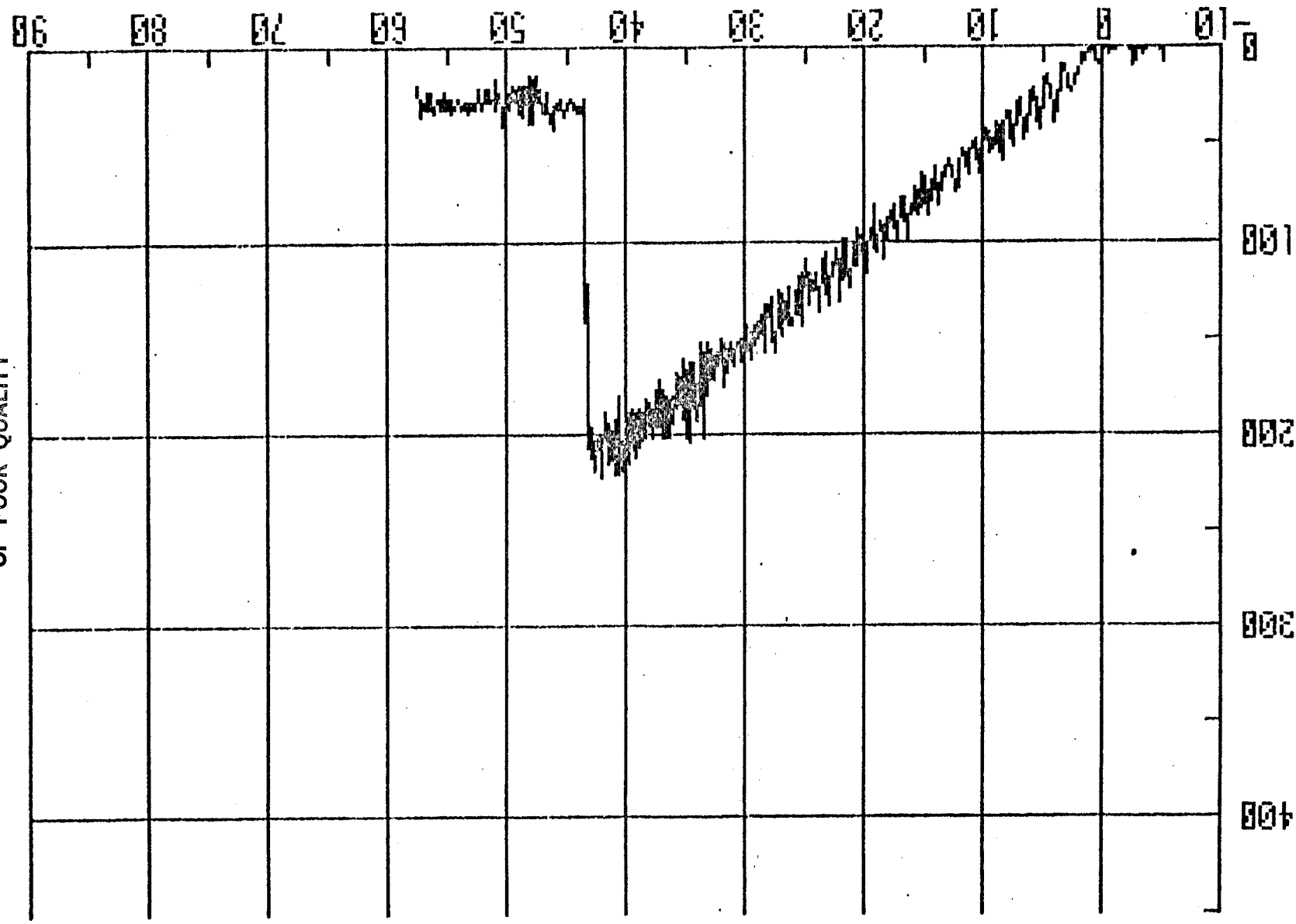
E-104

Filtered Coefficient of Friction



FRT#266 : Mon. K500-Stat. : SIC-Rot.

Normal Load (Lbf)



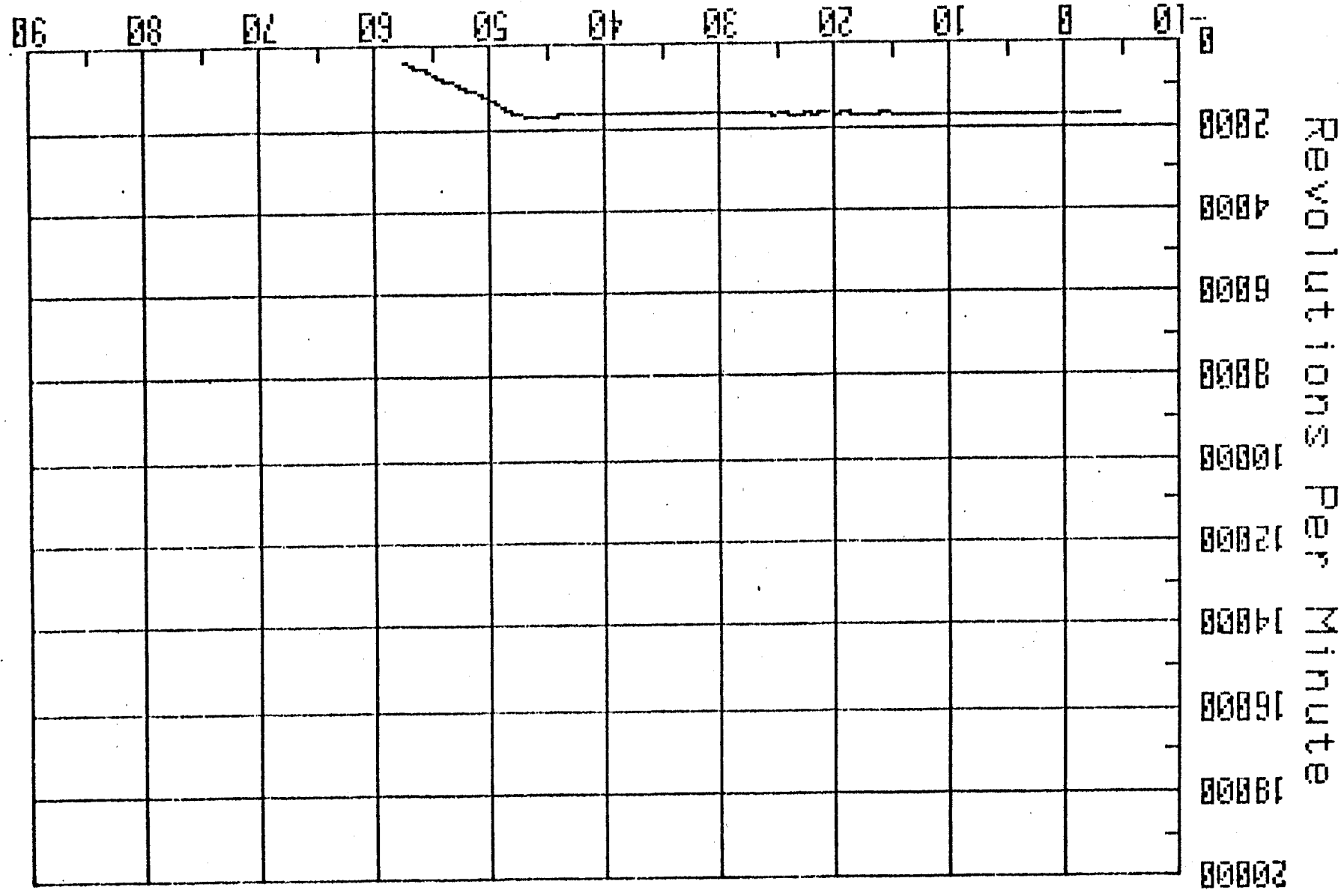
FRT#267: Mon. K500-Stat.; SIC-Rot.

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Time (seconds)

Load-time = 1.7 load offset.

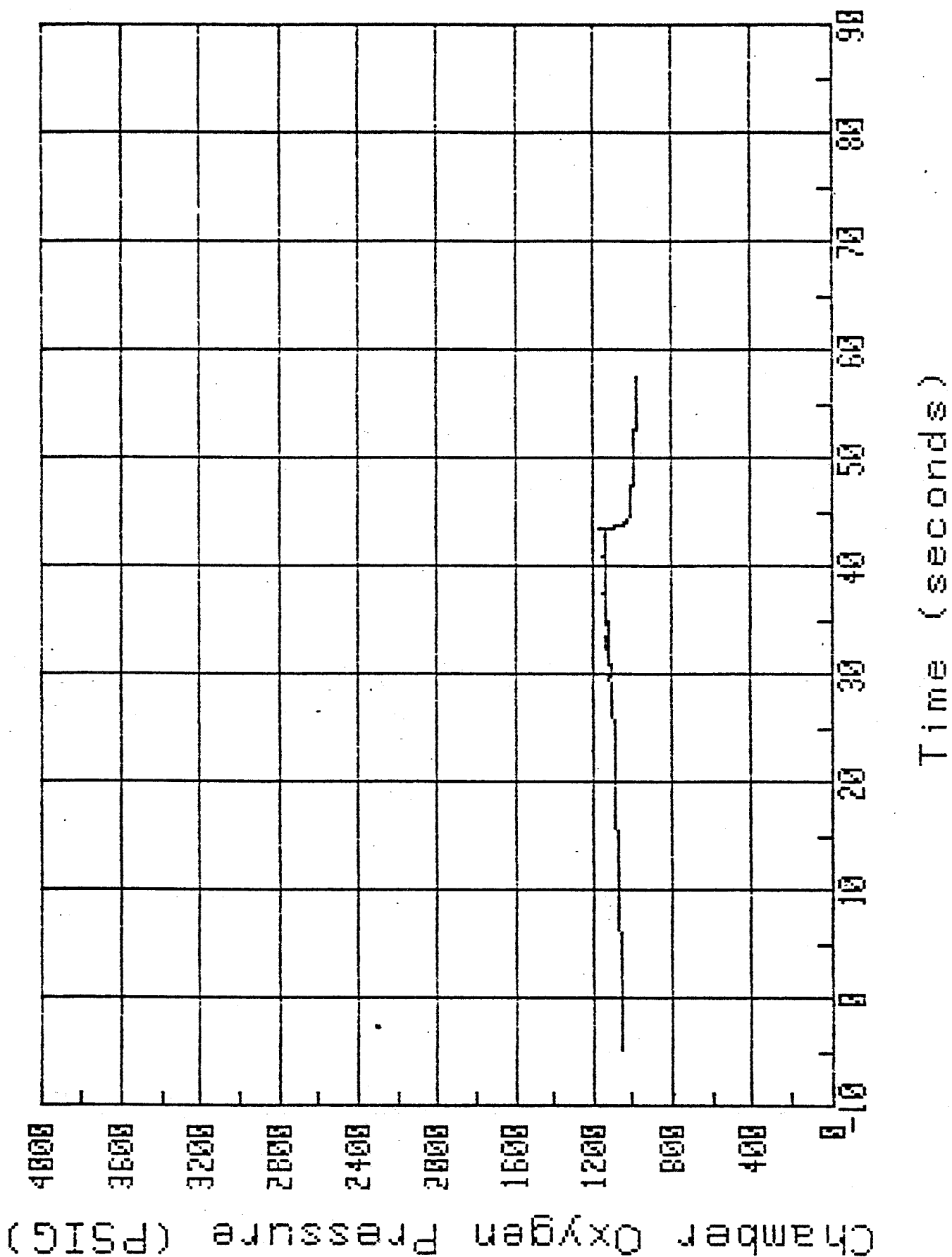
FRT#267: Mon. K500-Stat.: SIC-Rot.



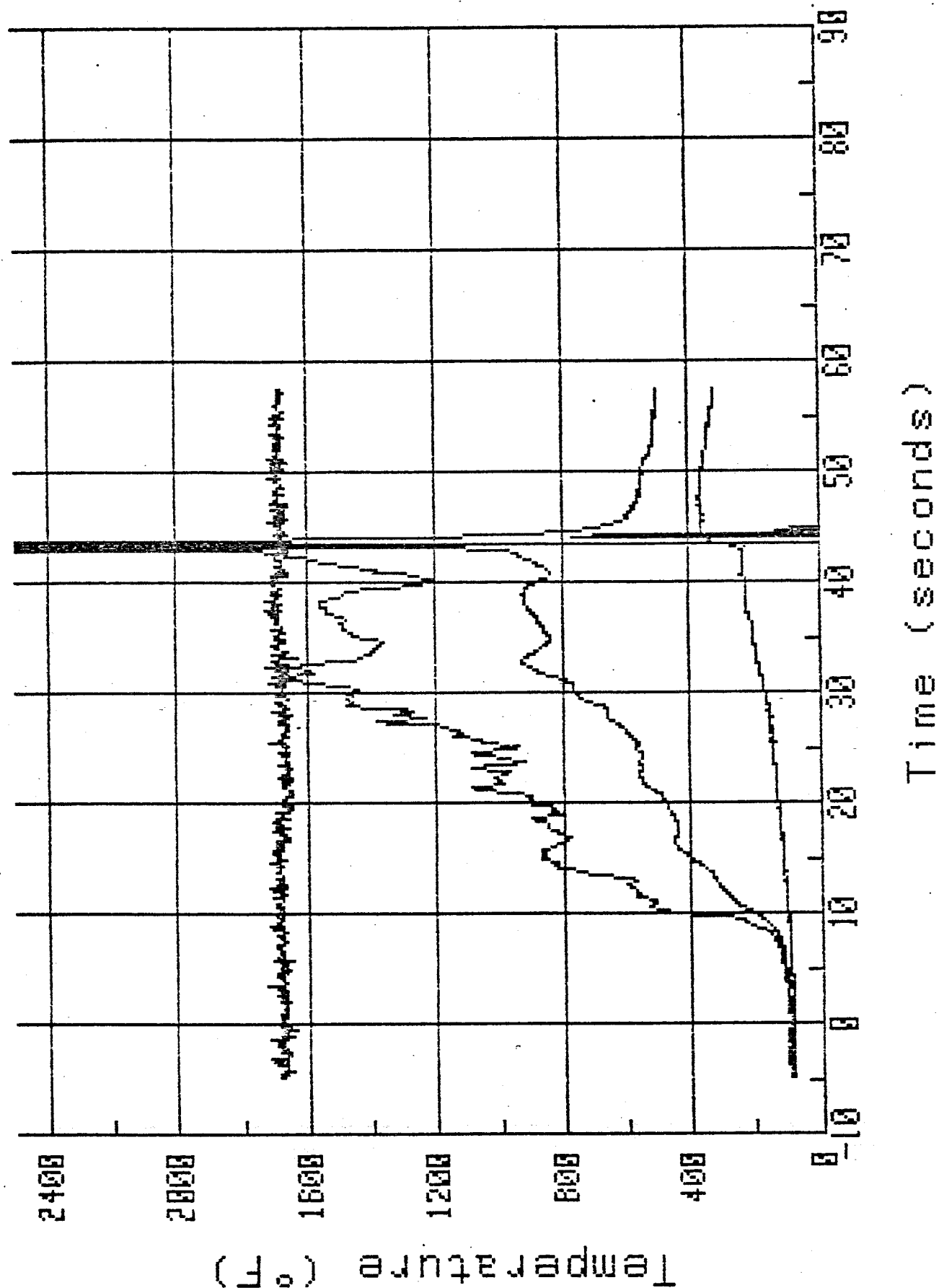
E-106

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FRT#267: Mon. K500-Stat.; SiC-Rot.

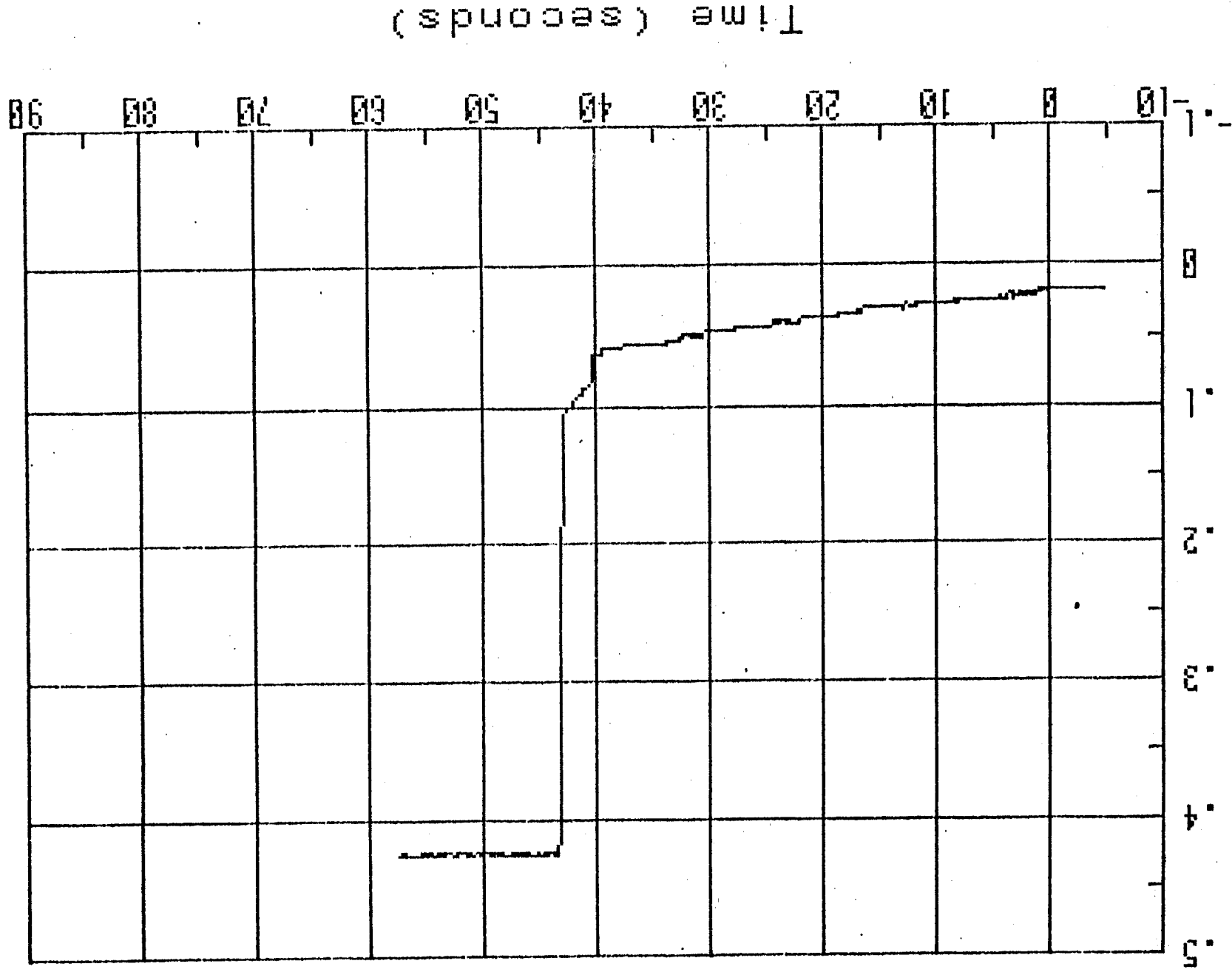


FRT#267: Mon. K500-Stat.; SiC-Rot.



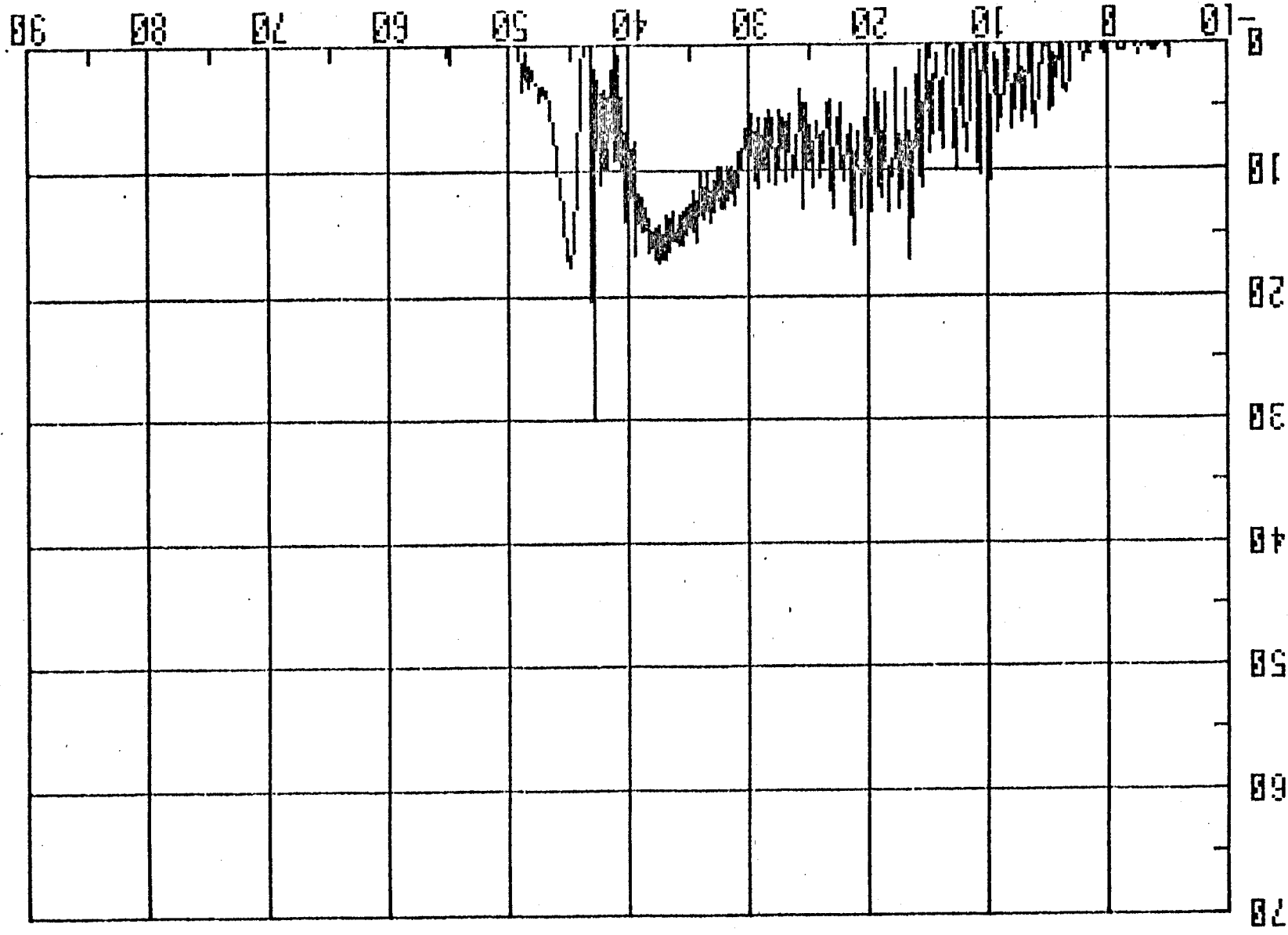
601-3

Sample Wear (Inches)



FRT#267: Mon. K500-Stat.: SIC-Rot.

FRT#267: Mon. K500-Stat.: SIC-Rot.



Time (seconds)

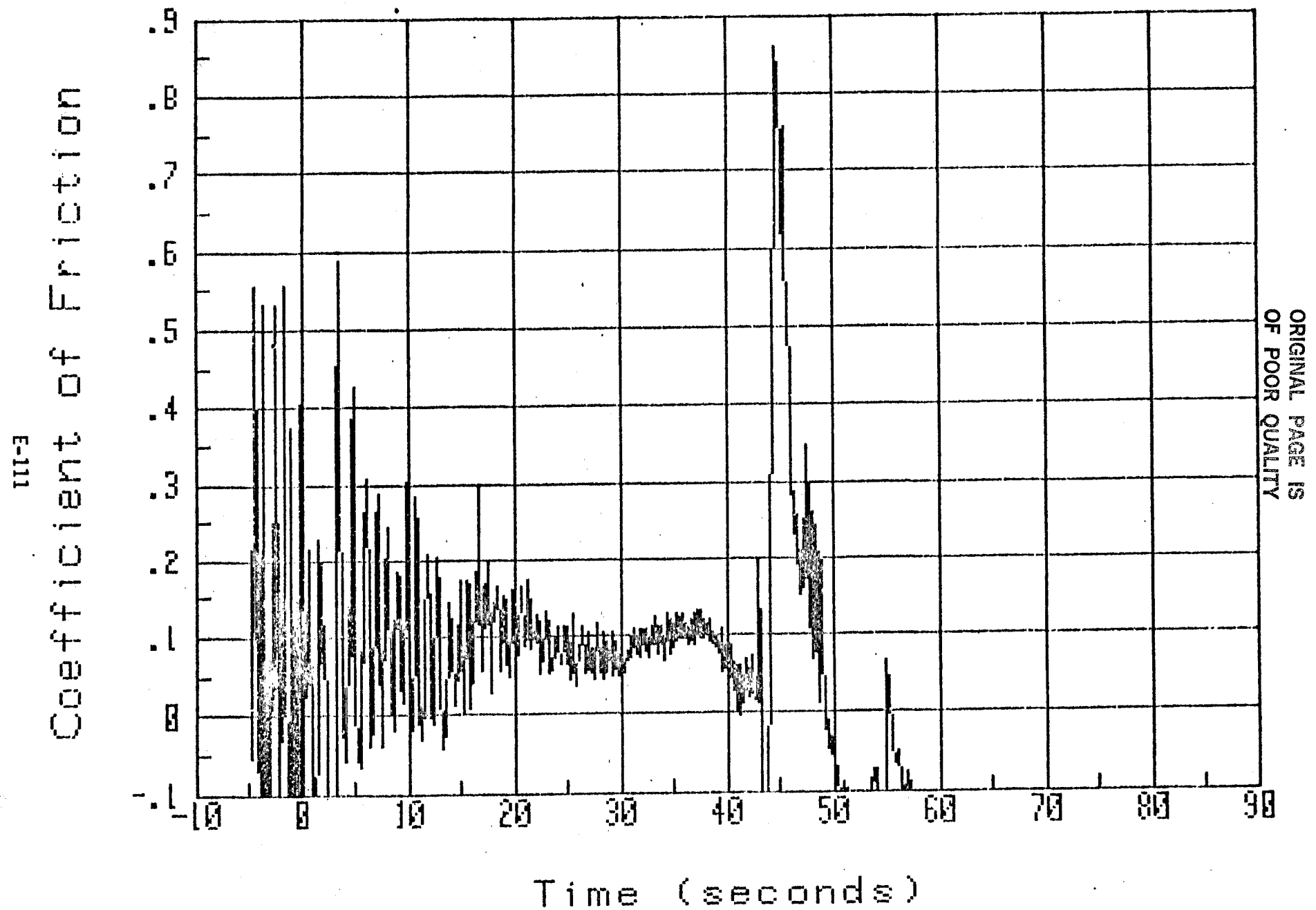
Torque Load (Lbf)

E-110

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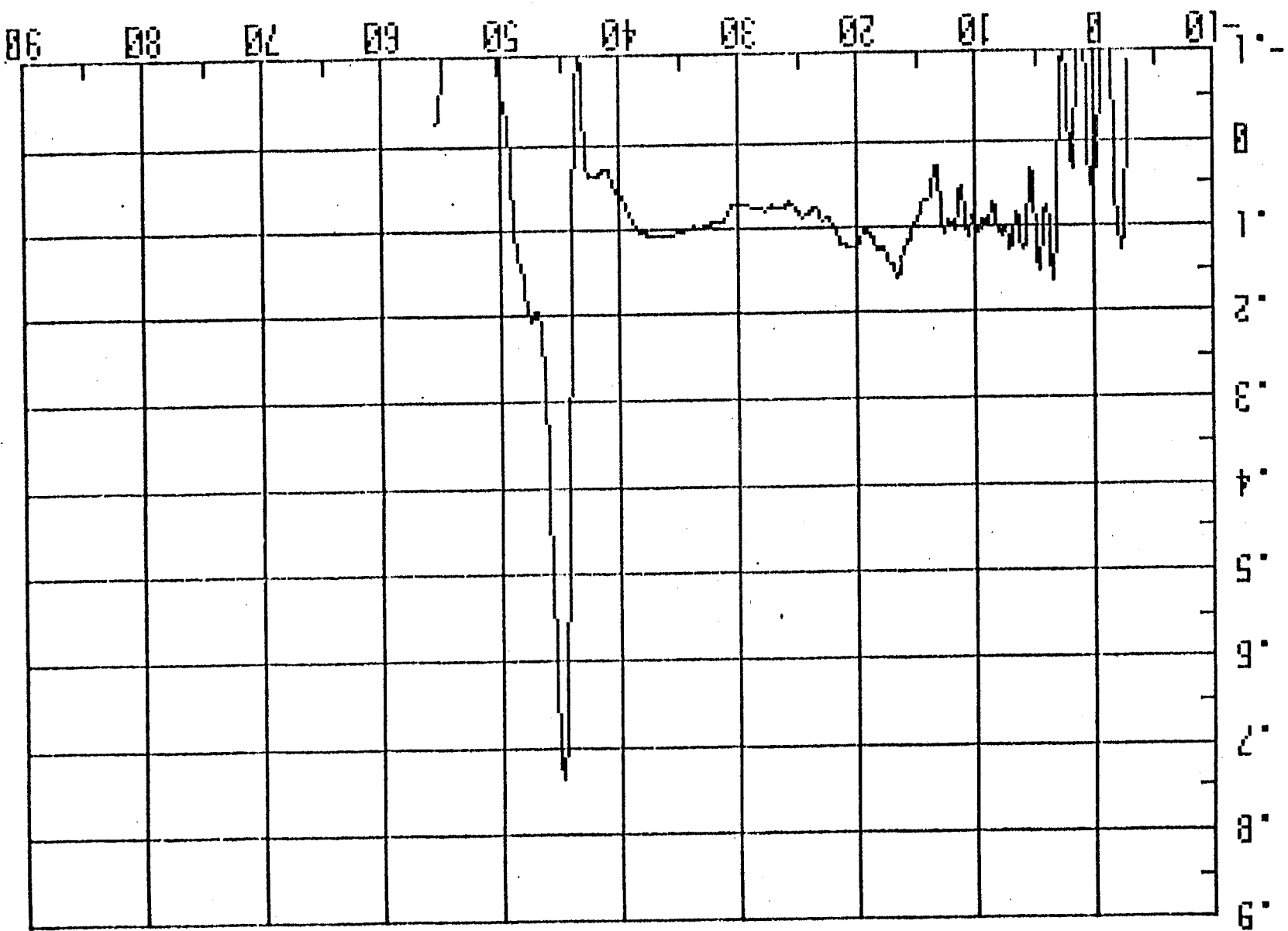
Contains a 48.7 load offset.

FRT#267: Mon. K500-Stat.; SiC-Rot.



Contains a torque load and a normal load offset.

Filtered Coefficient of Friction

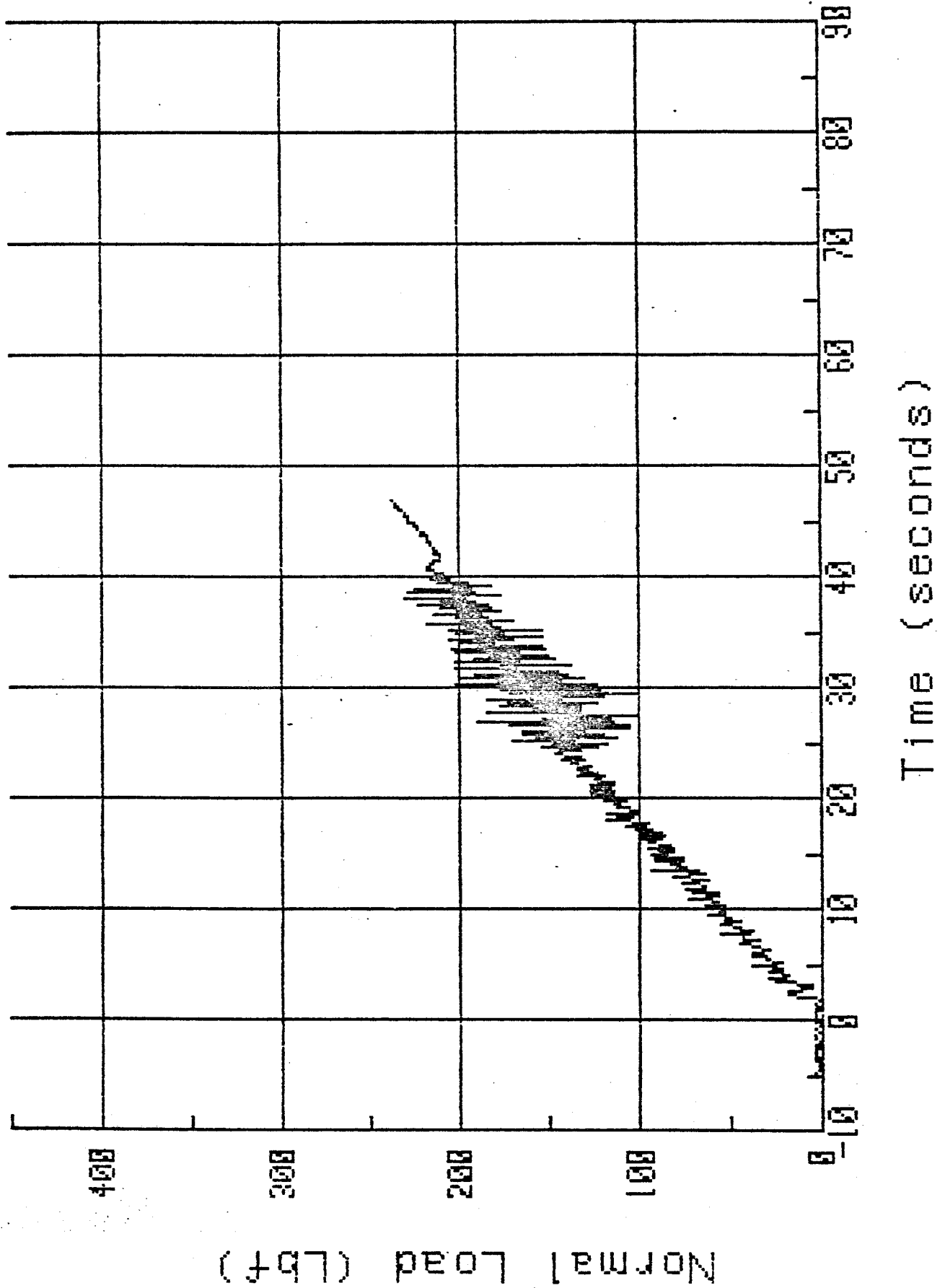


FRT#267: Mon. K500-Stat.: SIC-Rot.

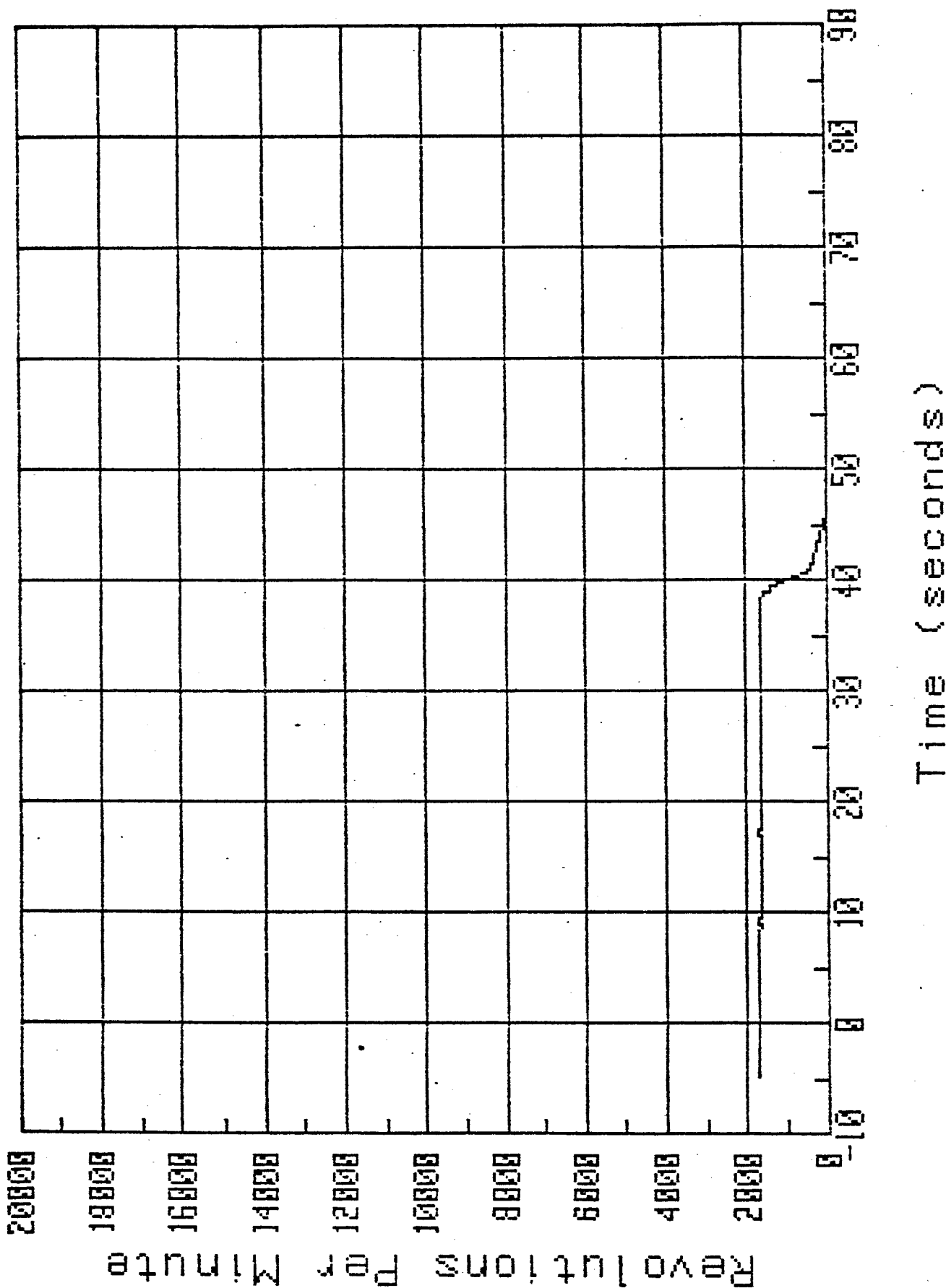
Time (seconds)

Positive & negative load and a normal load offset.

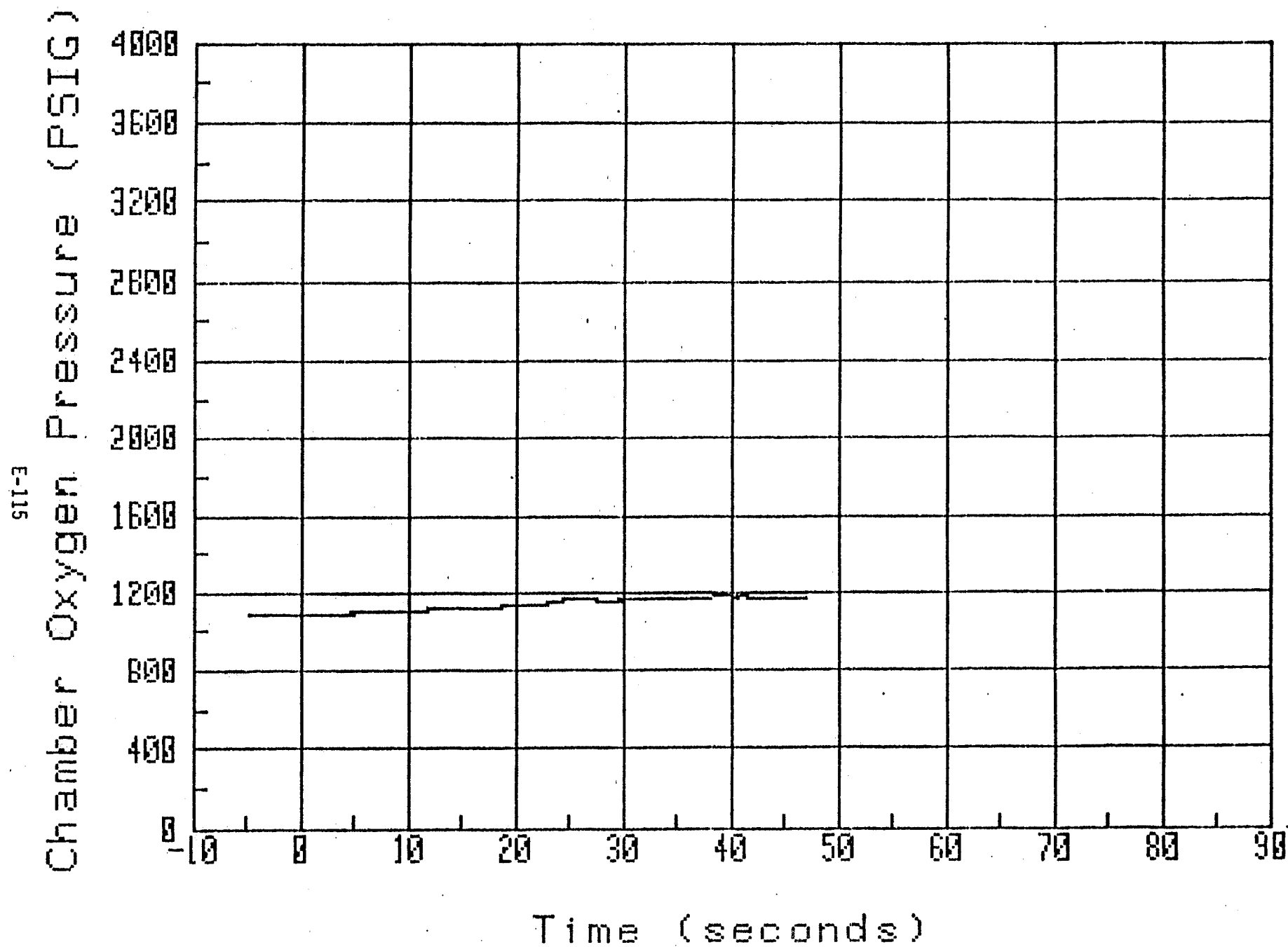
FRT#268: Mon. K500-Stat.; SiC-Rot.



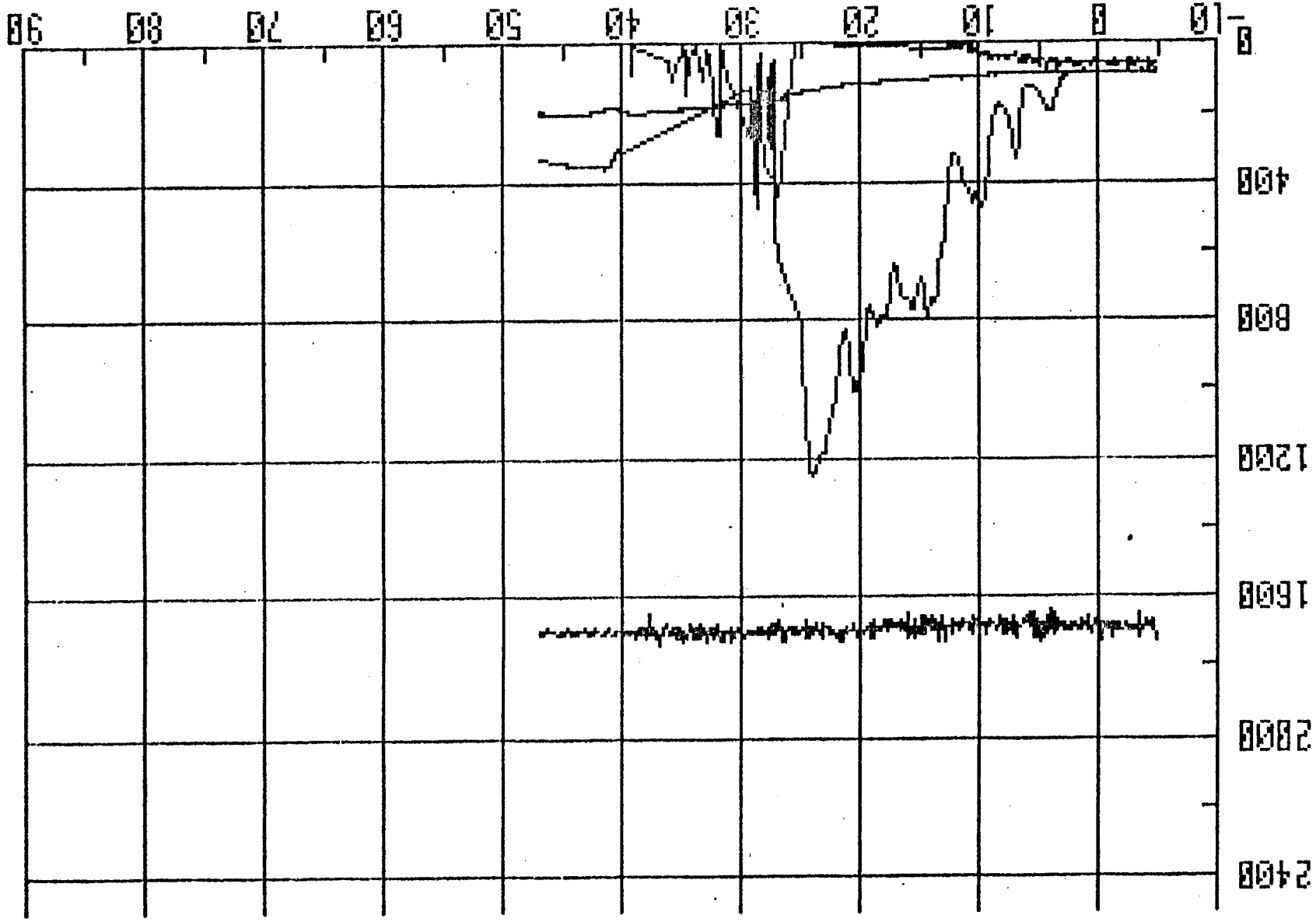
FRT#268: Mon. K500-Stat.; SiC-Rot.



FRT#268: Mon. K500-Stat.; SiC-Rot.



Temperature (°F)



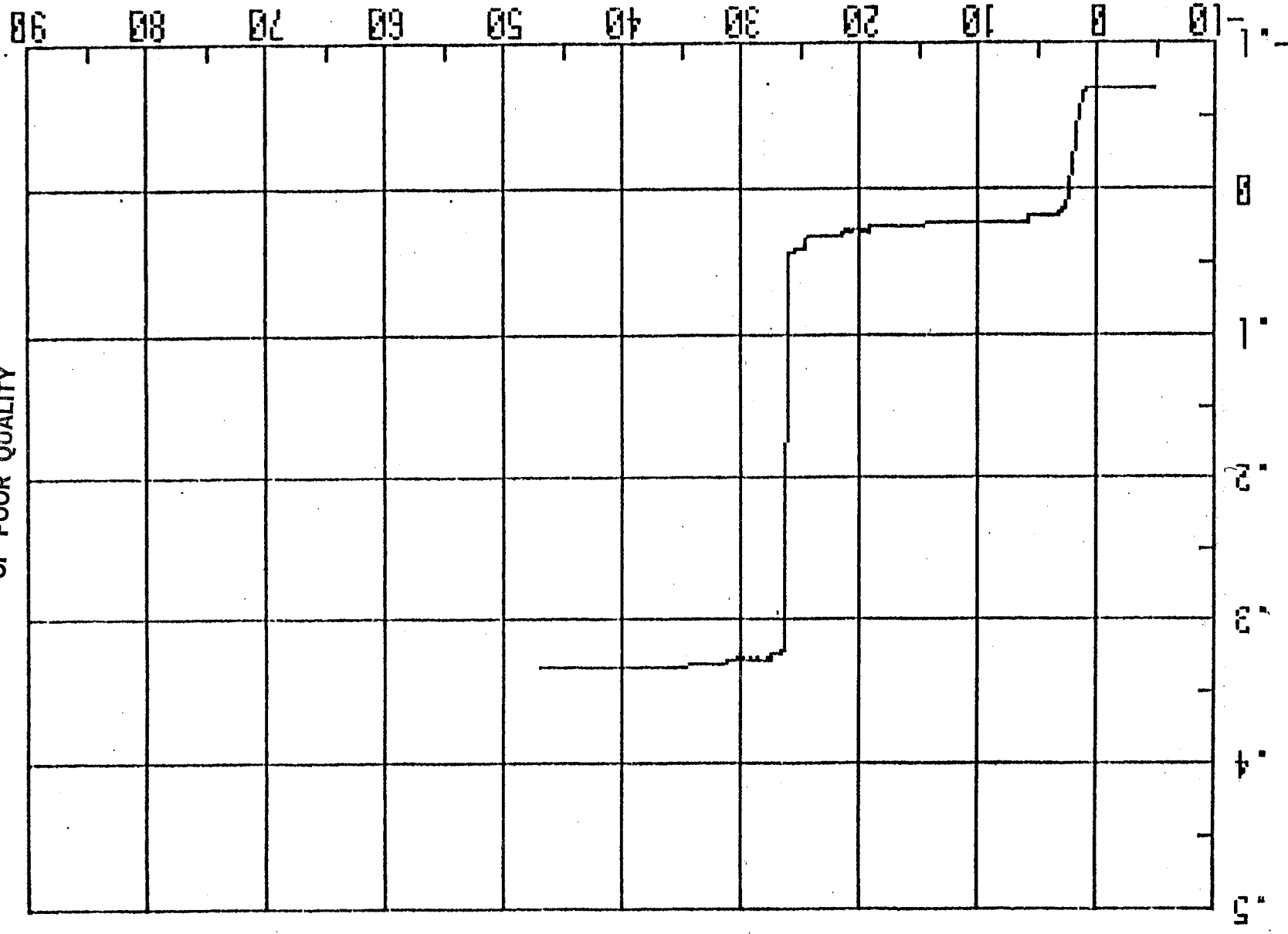
FRT#268: Mon. K500-Stat.; SIC-Rot.

Sample Wear (Inches)

E-117

Time (seconds)

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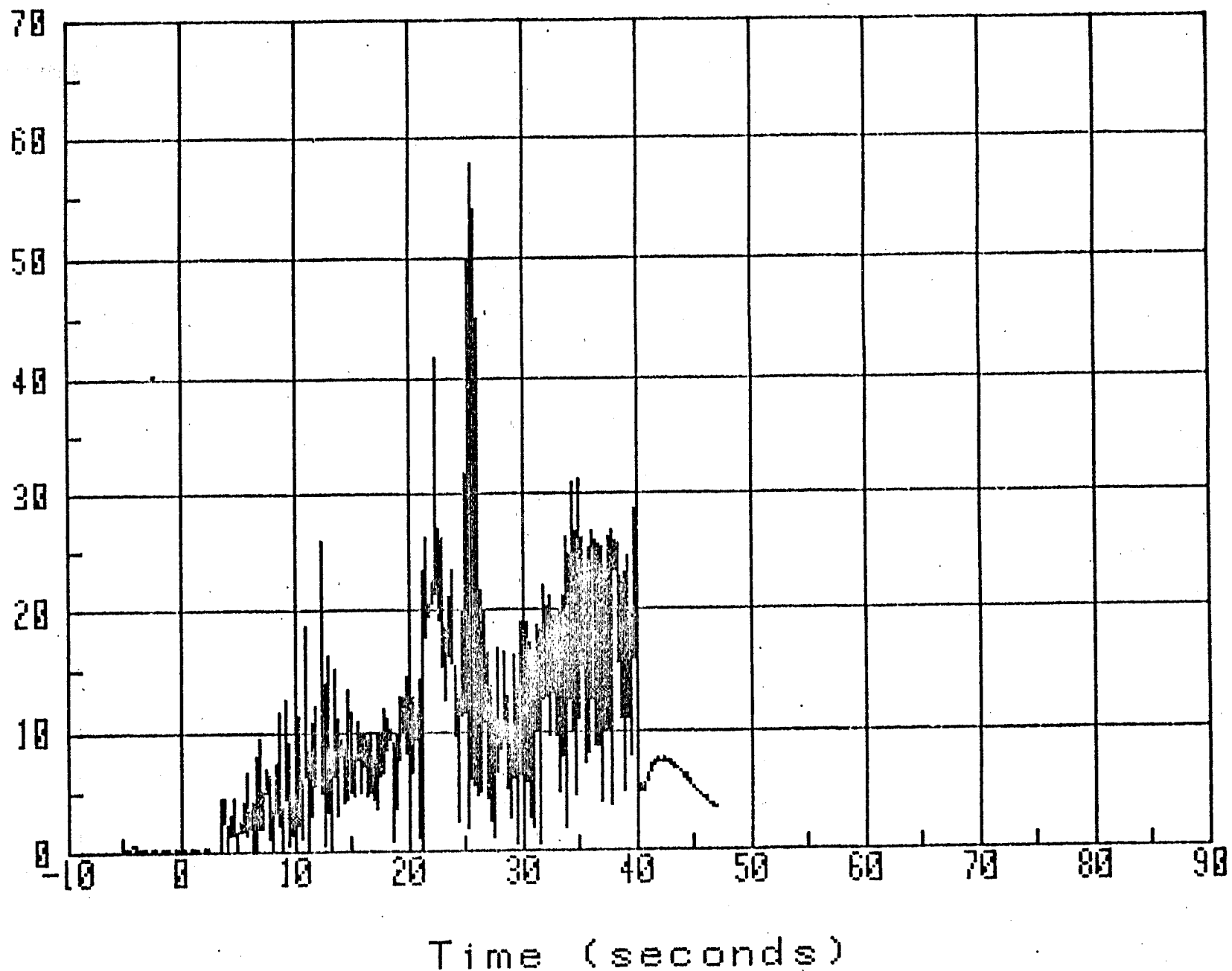
FRT#268: Mon. K500-Stat.; SIC-Rot.

FRT#268: Mon. K500-Stat.; SiC-Rot.

(f97) peo7 anbuoL

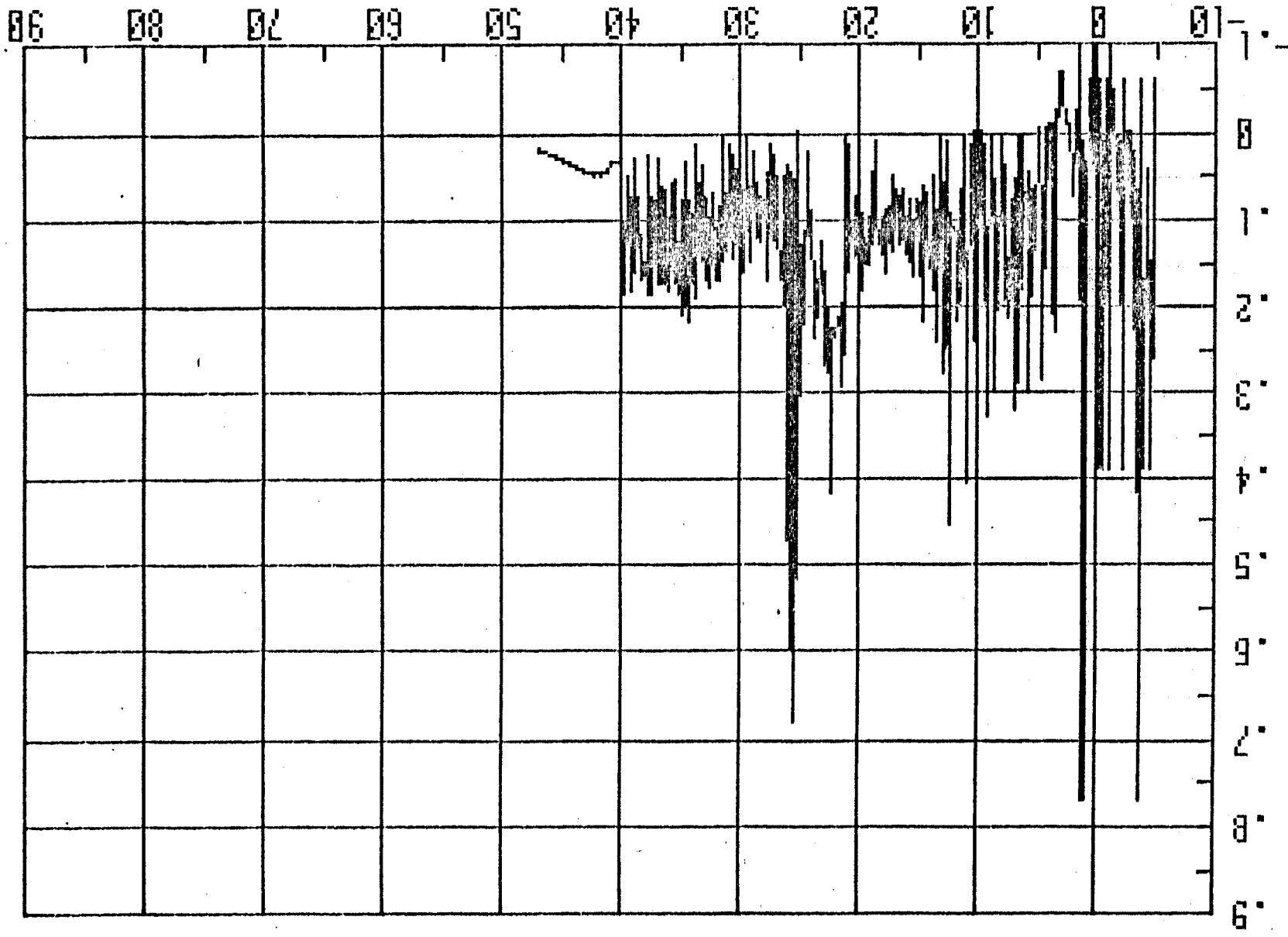
E-118

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Contains a +6.5 load offset.

Coefficient of Friction



FRT#268 : Mon. K500-Stat. : SIC-Rot.

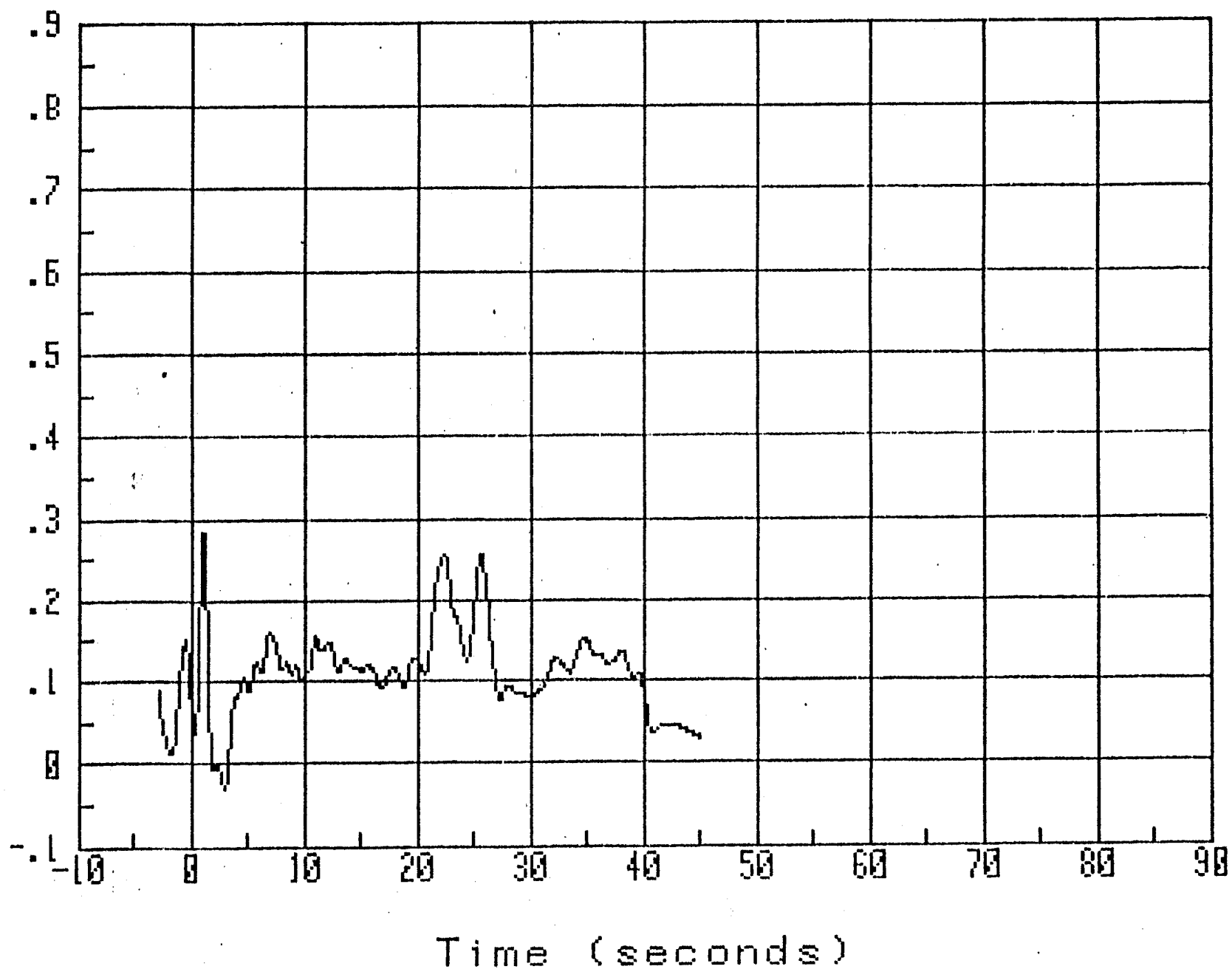
Time (seconds)

Containing a torque load and a normal load offset.

ORIGINAL PAGE IS
OF POOR QUALITY

FRT#268: Mon. K500-Stat.; SiC-Rot.

Filtered Coefficient of Friction
E-120

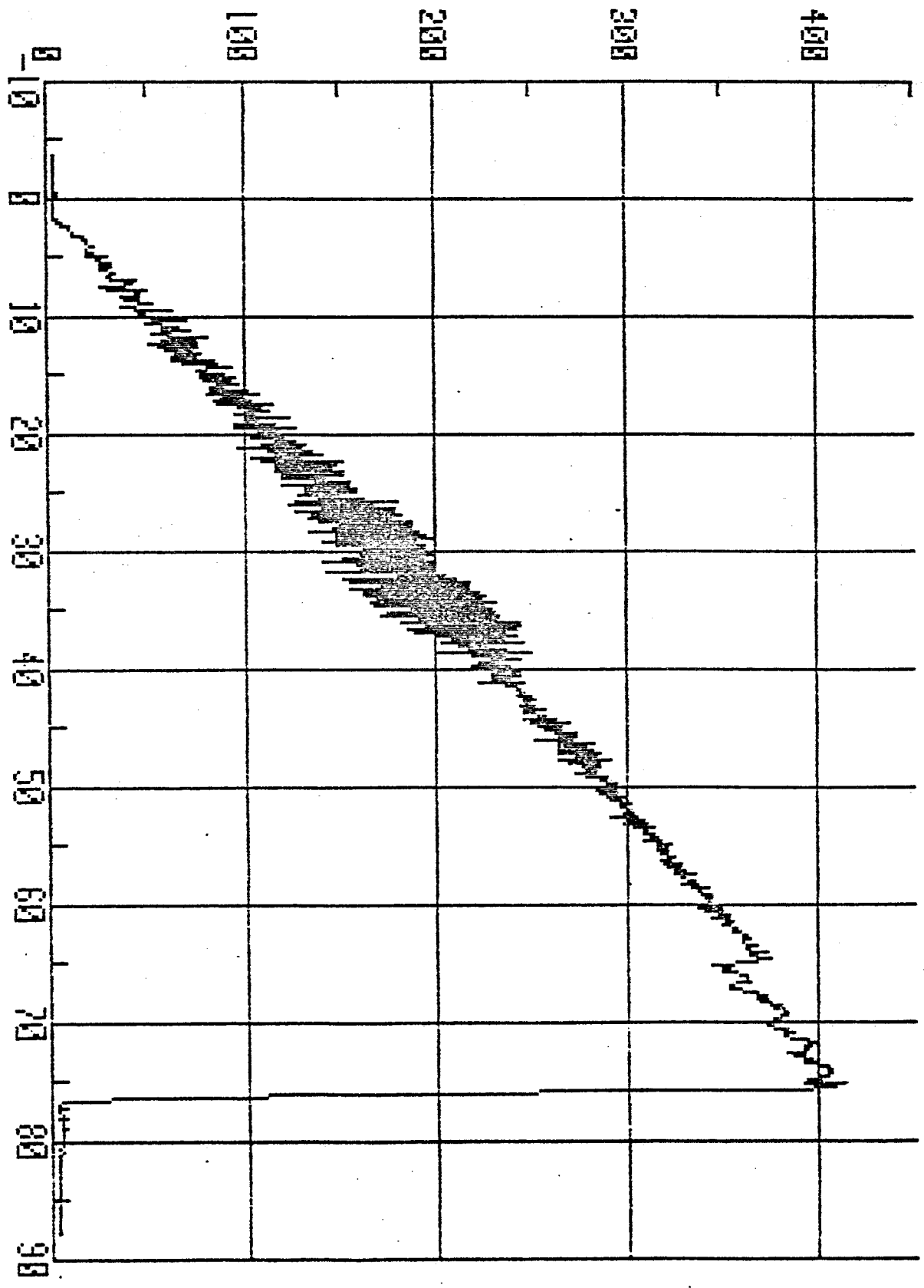


Contains a torque load and a normal load offset.

FRT#272: E1ecP1Ni-Stat.; Mon. K500-Rot.

E-121

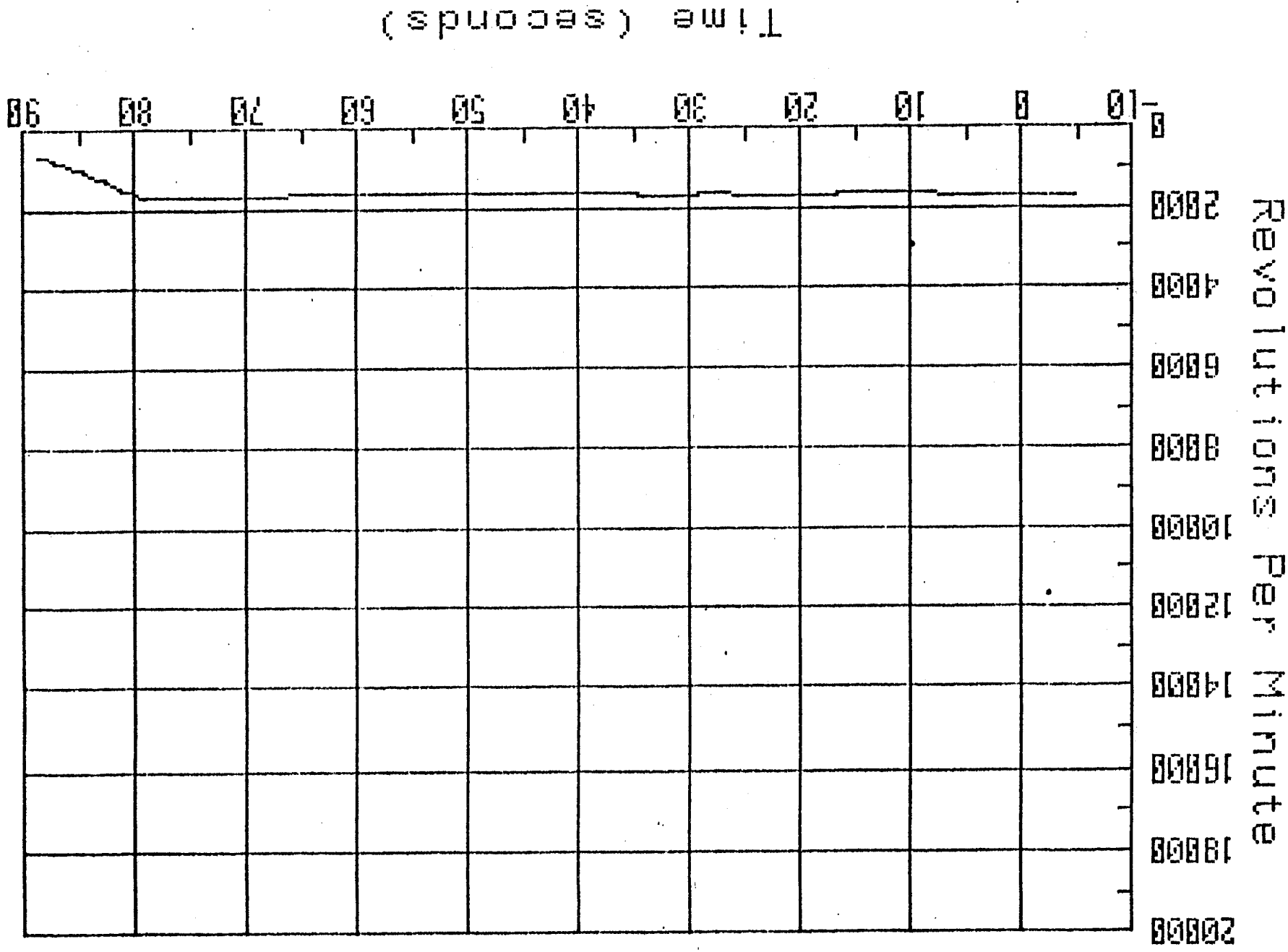
Normal Load (Lbf)



Time (seconds)

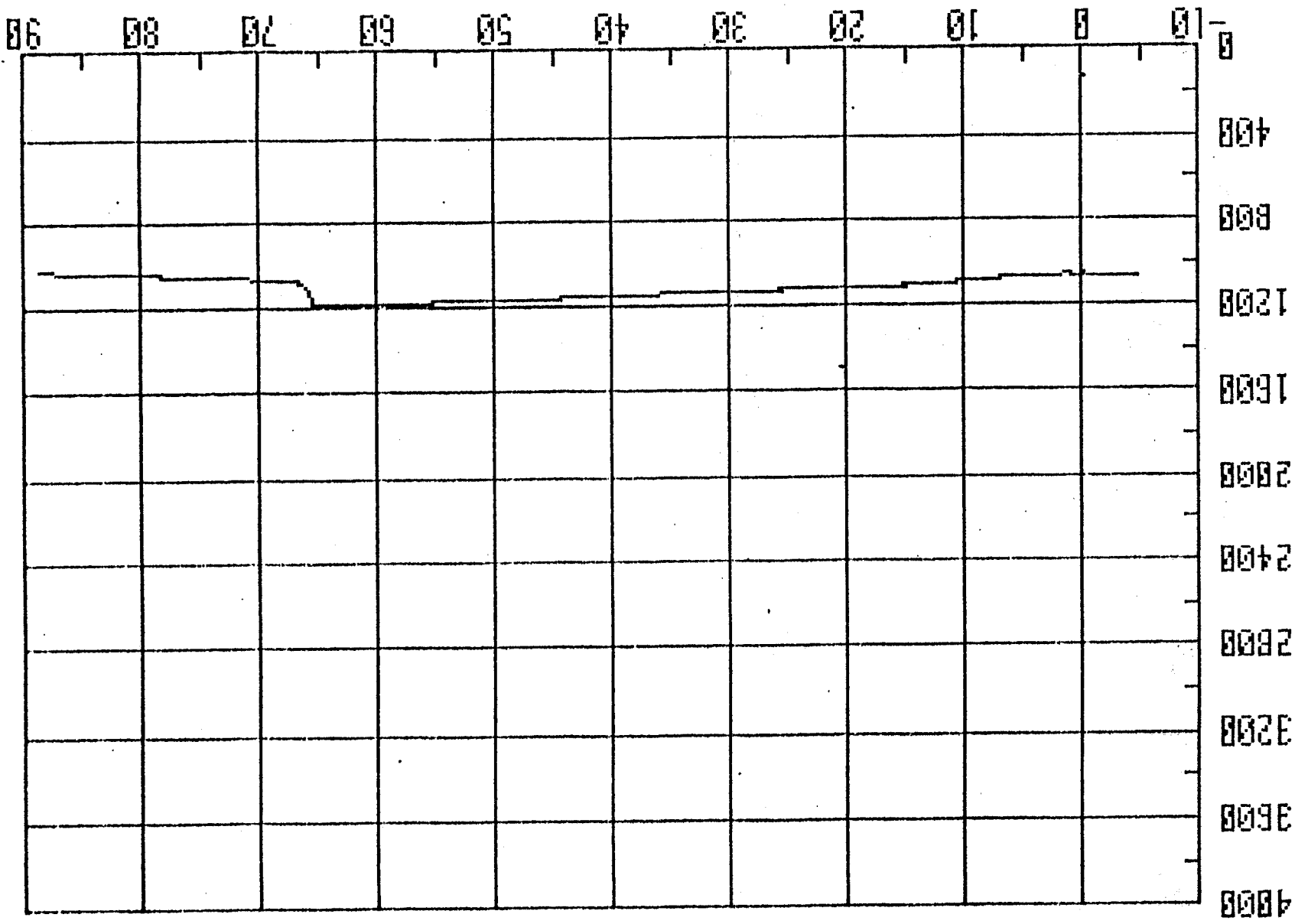
ORIGINAL PAGE IS
OF POOR QUALITY

E-122



FRT#272: ElecP1N1-Stat.; Mon. K500-Rot.

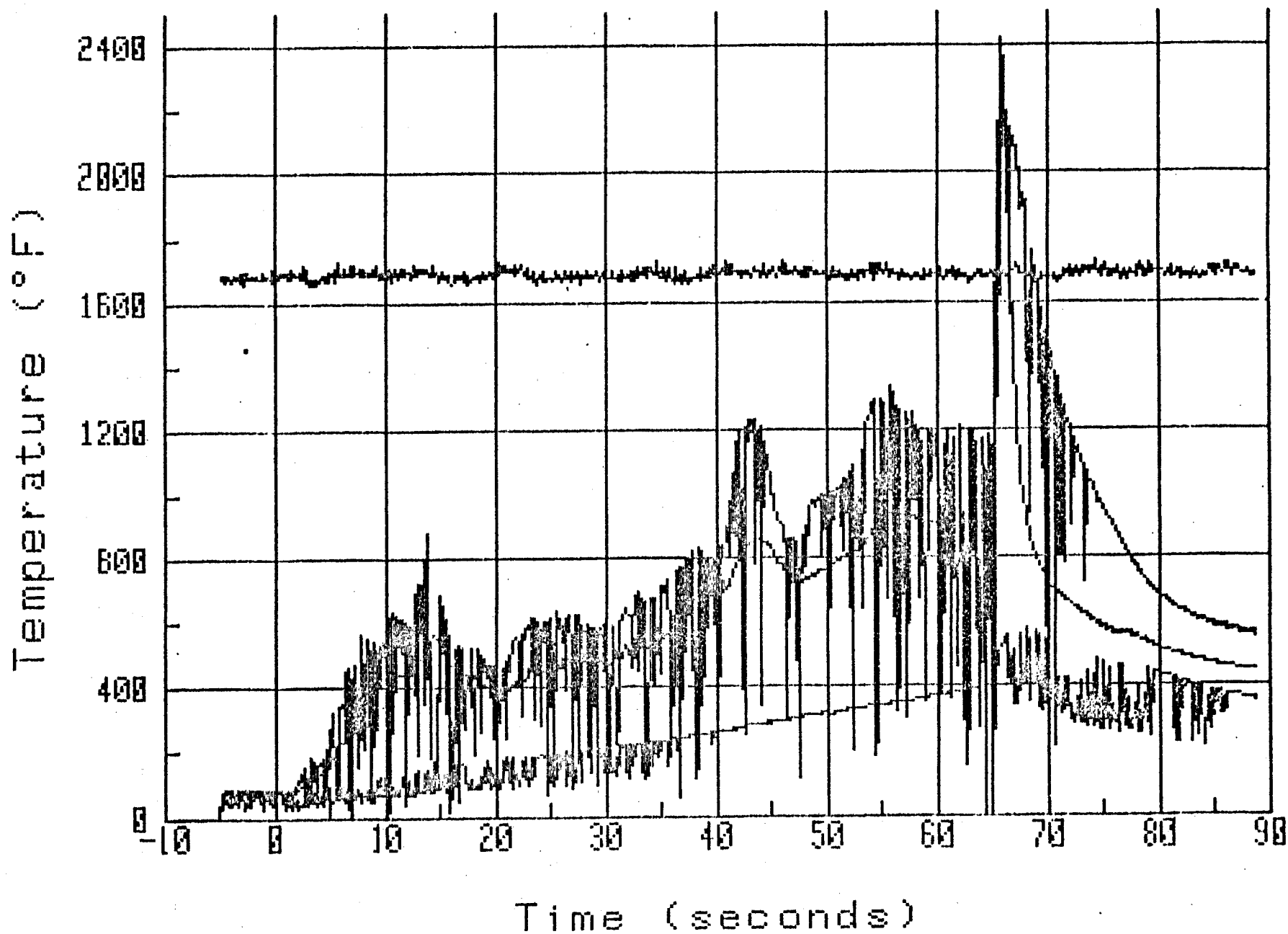
Chamber Oxygen Pressure (PSIG)



Time (seconds)

FRT#272: E1ecP1N1-St at. ; Mon. K500-Rot.

FRT#272: ElecP1Ni-Stat.; Mon. K500-Rot.



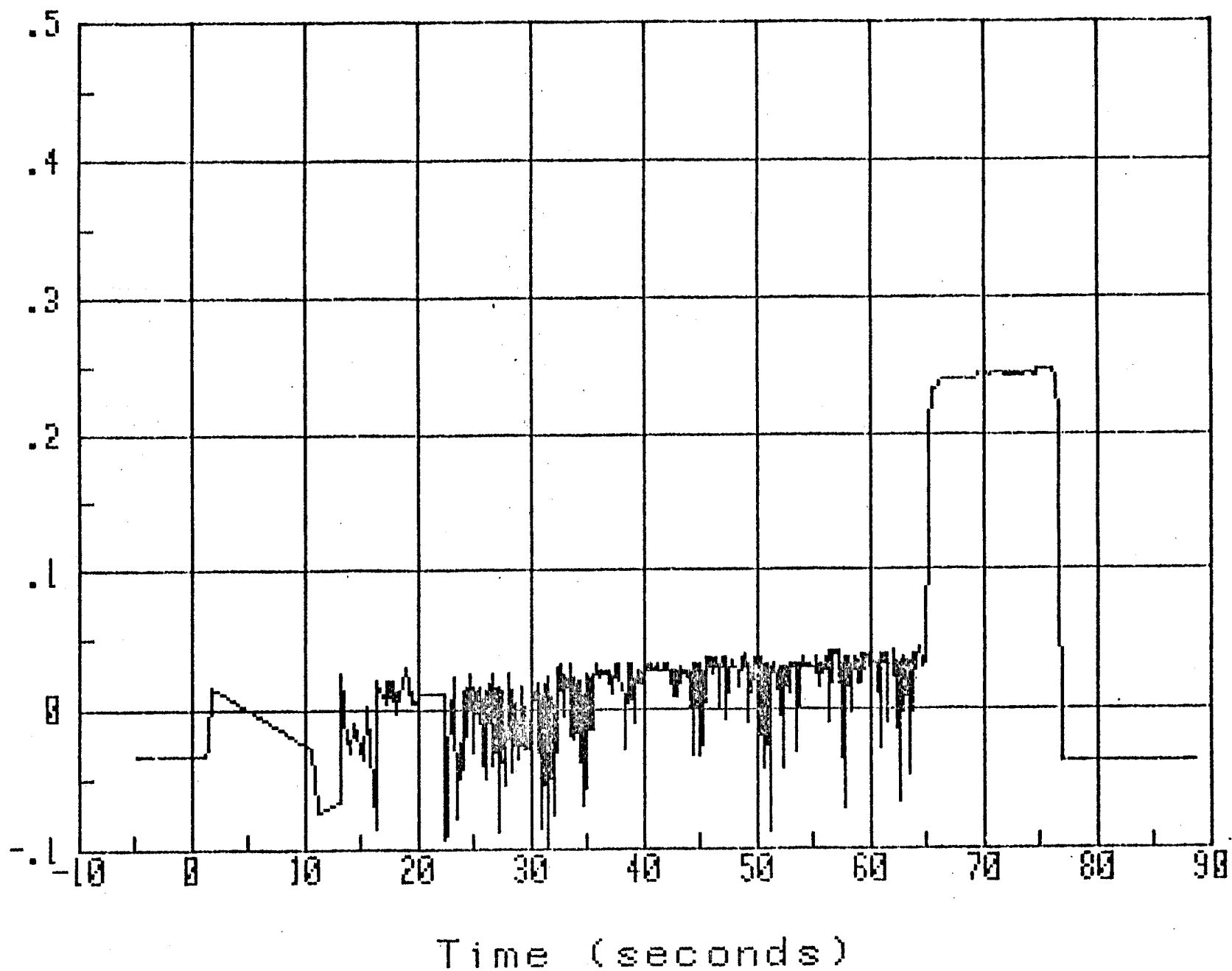
E-124

ORIGINAL
PAGE 15
OF POOR
QUALITY

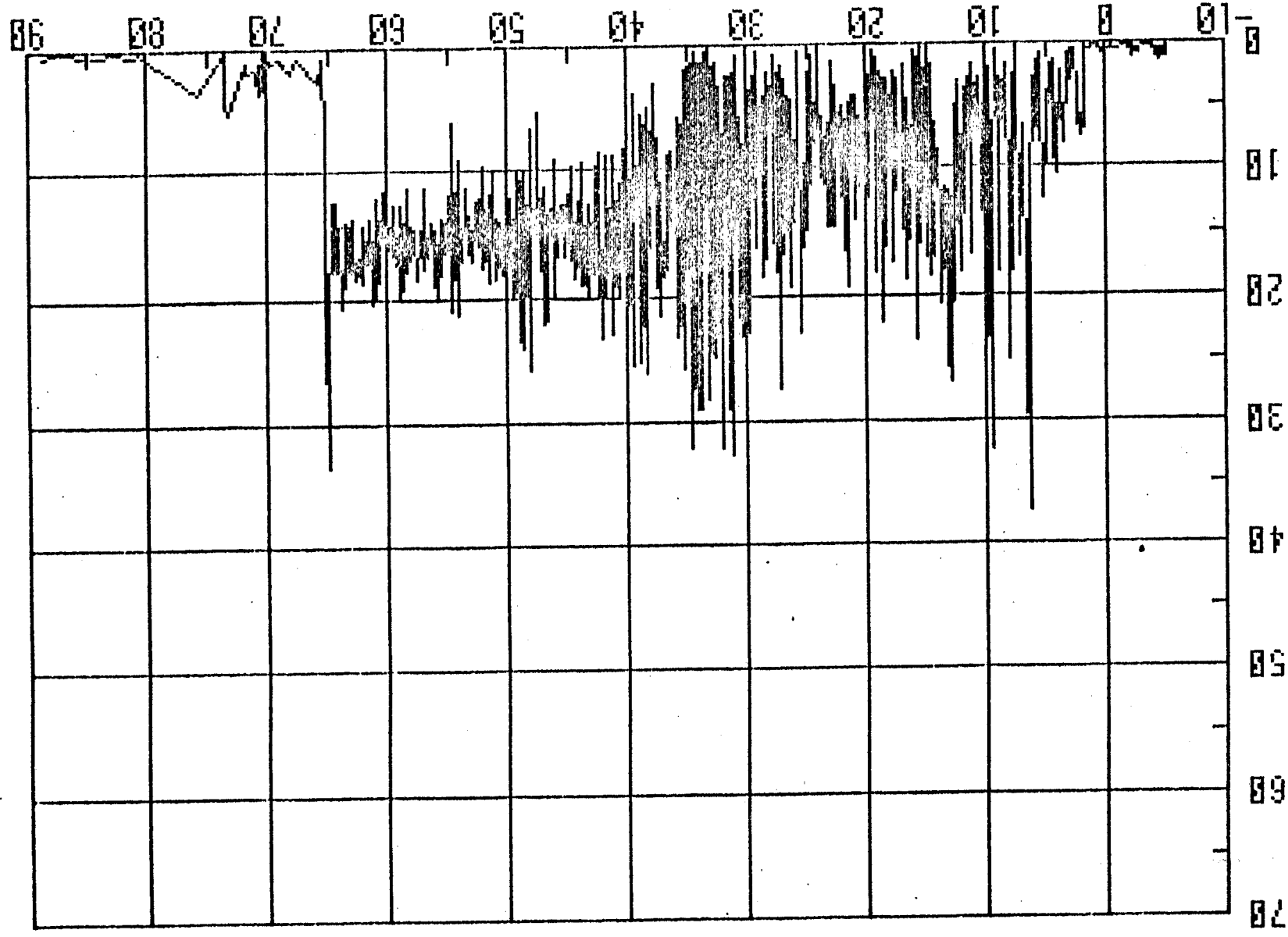
FRT#272: ElecP1Ni-Stat.; Mon. K500-Rot.

E-125

Sample Wear (Inches)



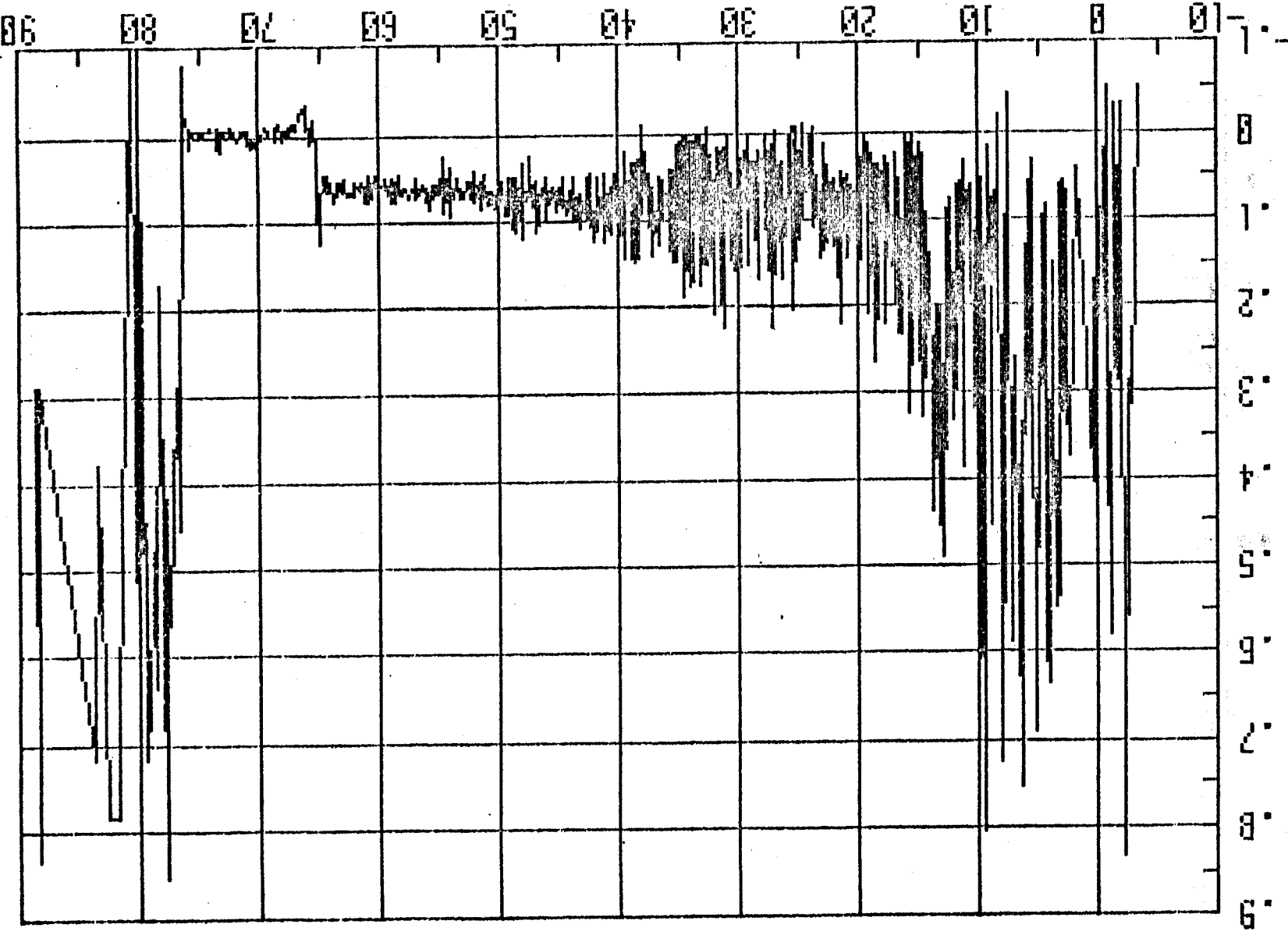
FRT#272: E1ecP1N1-Stat.; Mon. K500-Rot.



Coefficient of Friction

E-127

ORIGINAL POSITION
OF POOR QUALITY



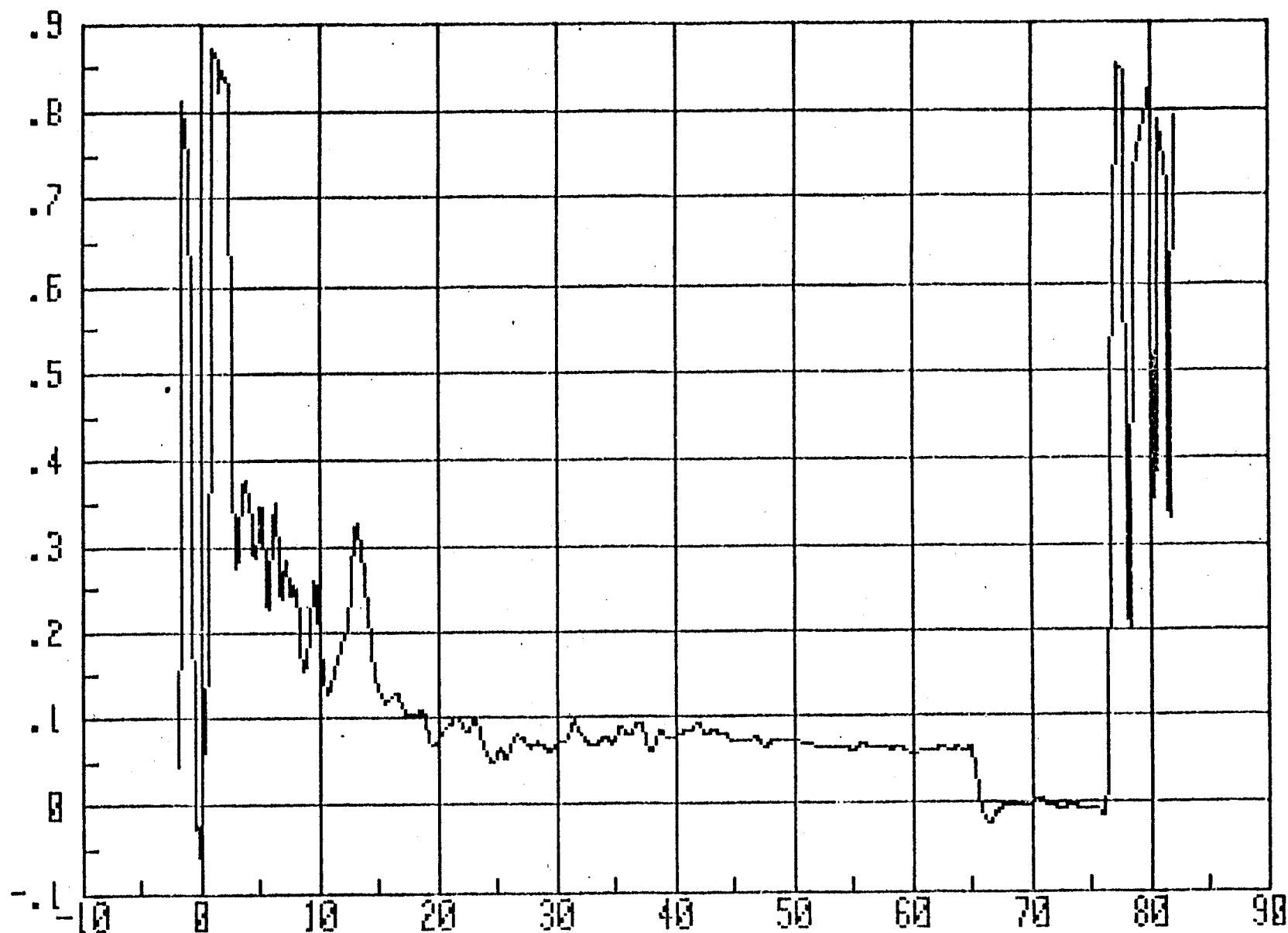
Time (seconds)

Contains a torque load and a normal load offset.

FRT#272: E1ecP1N1-Stat.; Mon. K500-Rot.

FRT#272: ElecP1Ni-Stat.; Mon. K500-Rot.

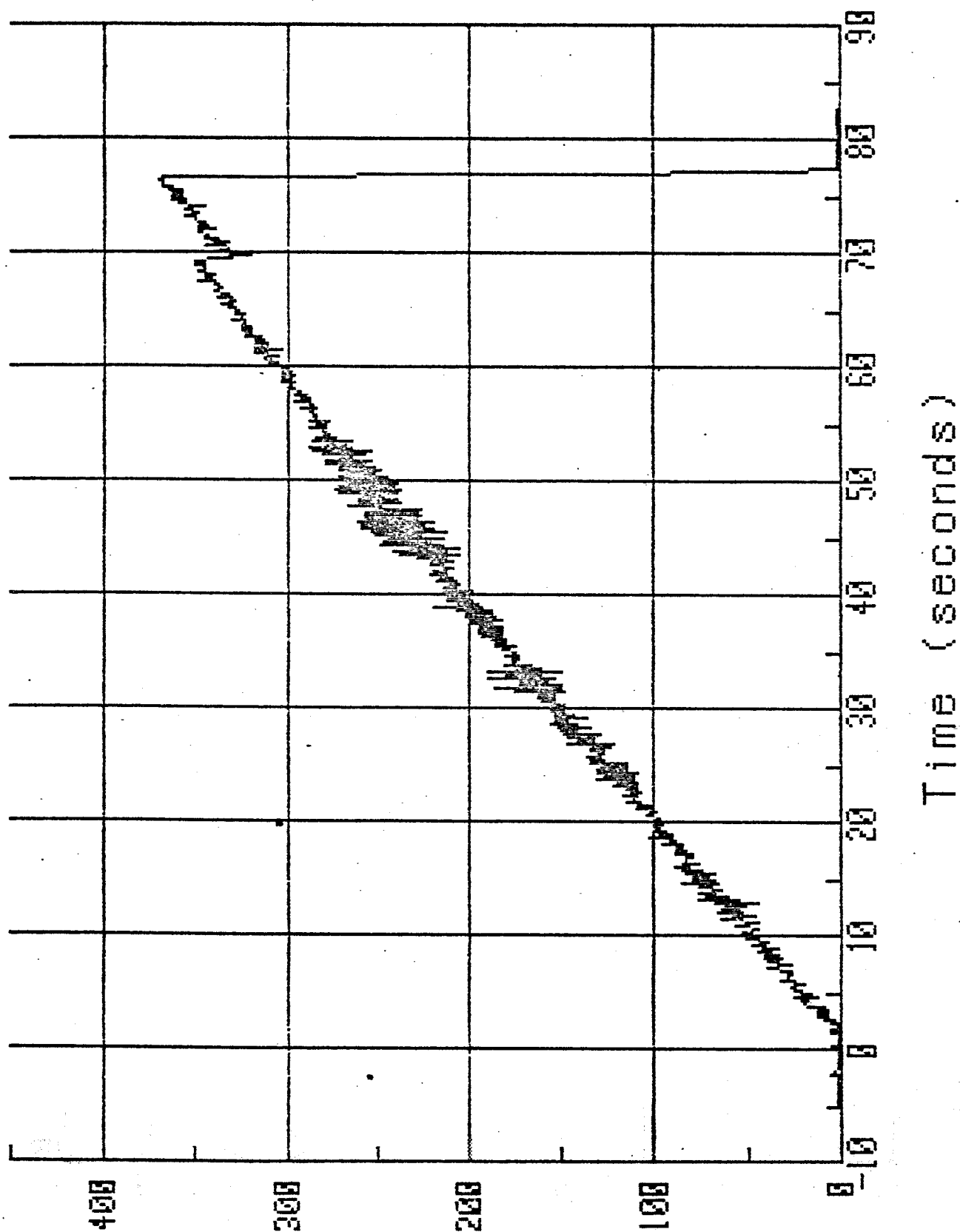
Filtered Coefficient of Friction



Time (seconds)

Contains a torque load and a normal load offset.

FRT#273: ElecP1Ni-Stat.; Mon. K500-Rot.



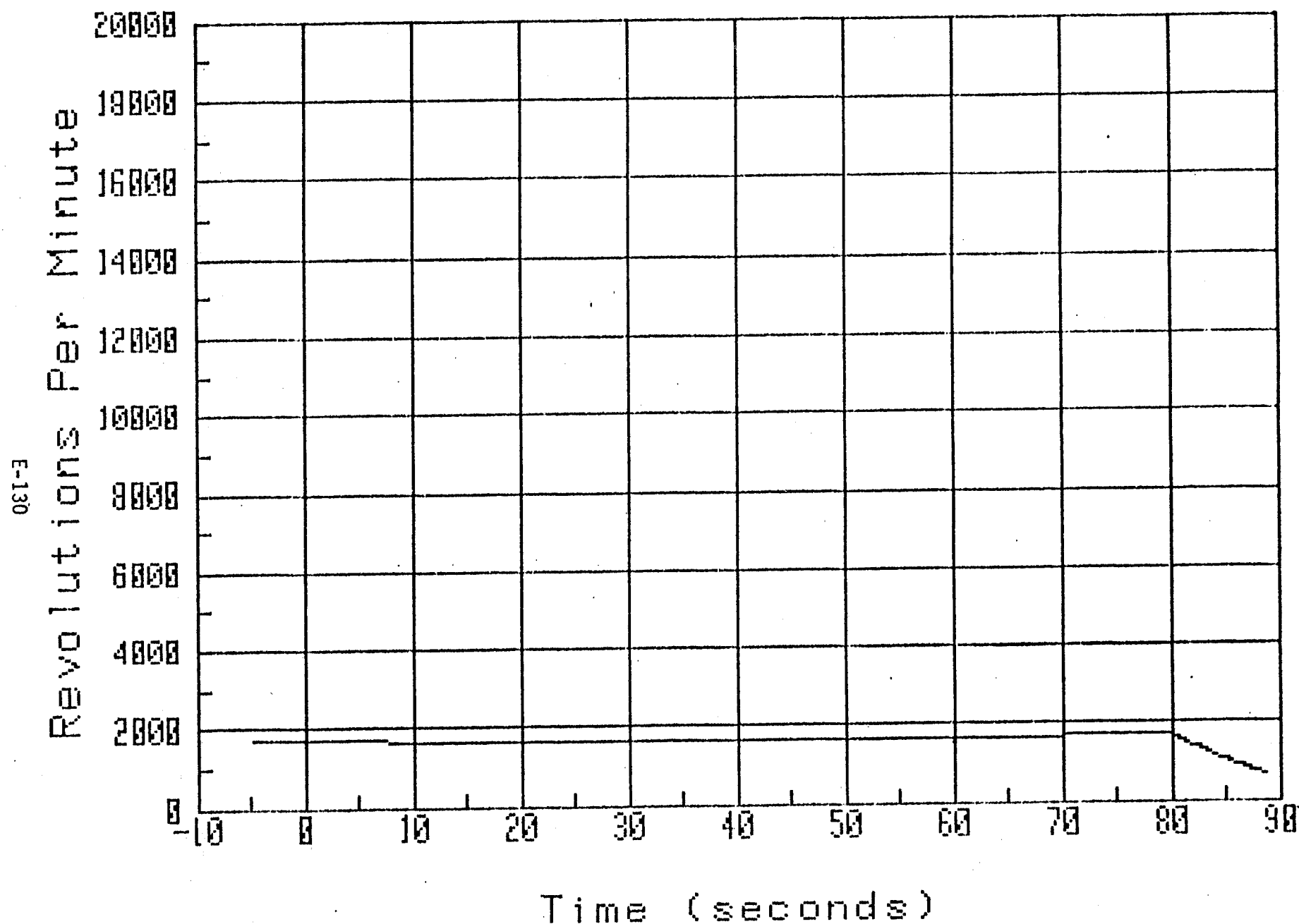
(+97) peot [ewon

E-129

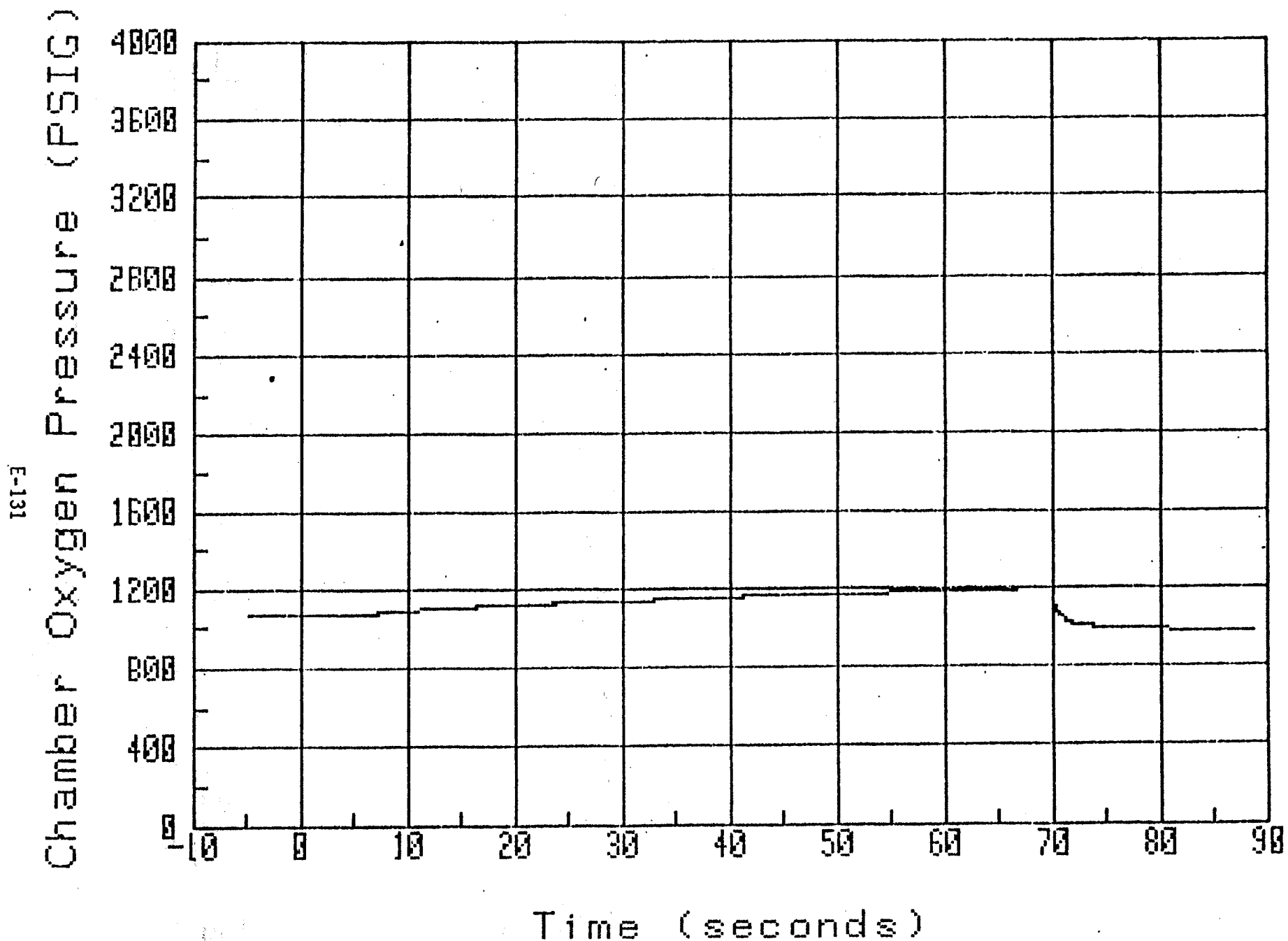
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OF POOR QUALITY

Continue at -7.1 load offset.

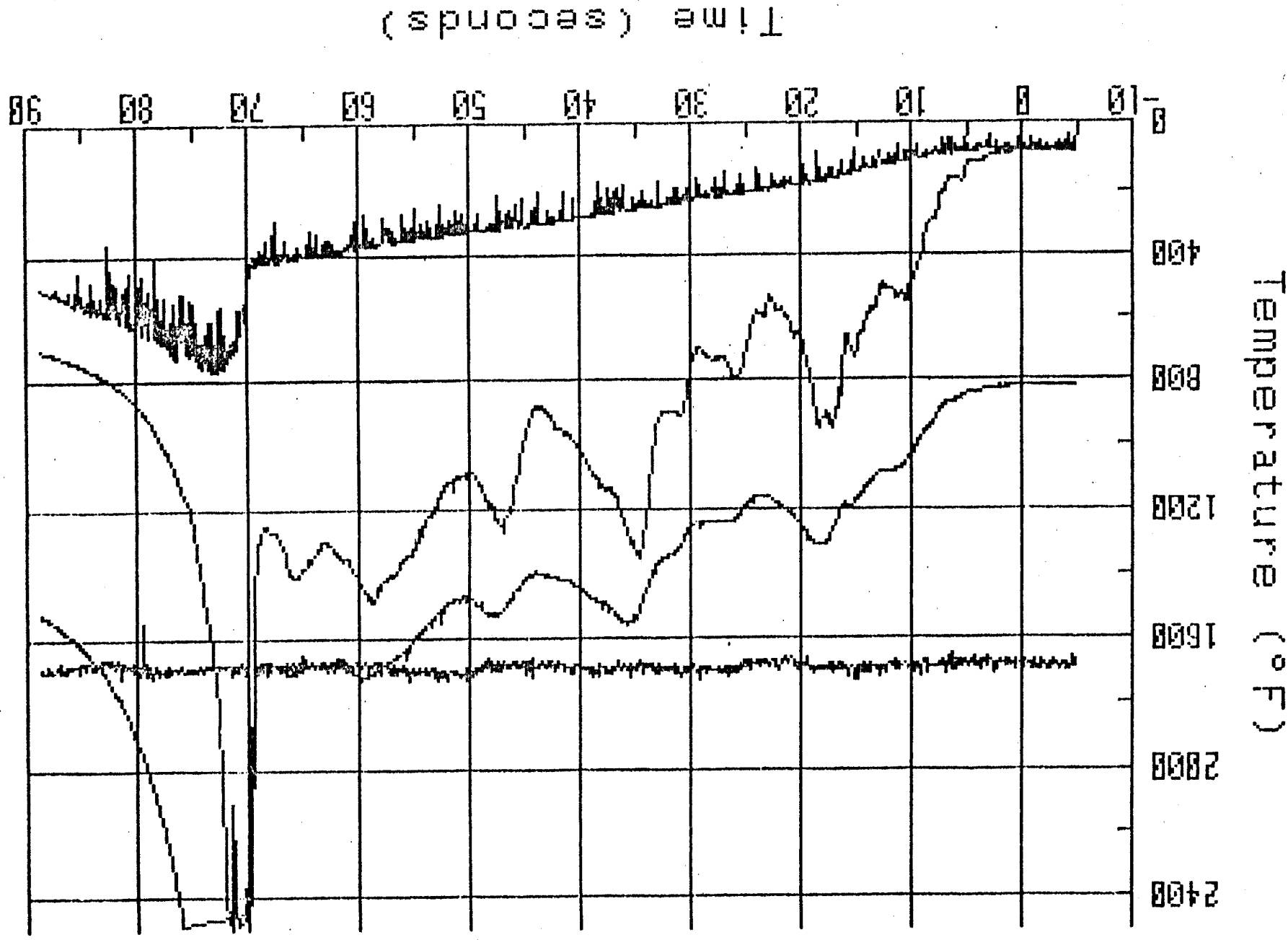
FRT#273: ElecP1Ni-Stat.; Mon. K500-Rot.



FRT#273: ElecP1Ni-Stat.; Mon. K500-Rot.



FRT#273: ElecP1N1-Stat.: Mon. K500-Rot.

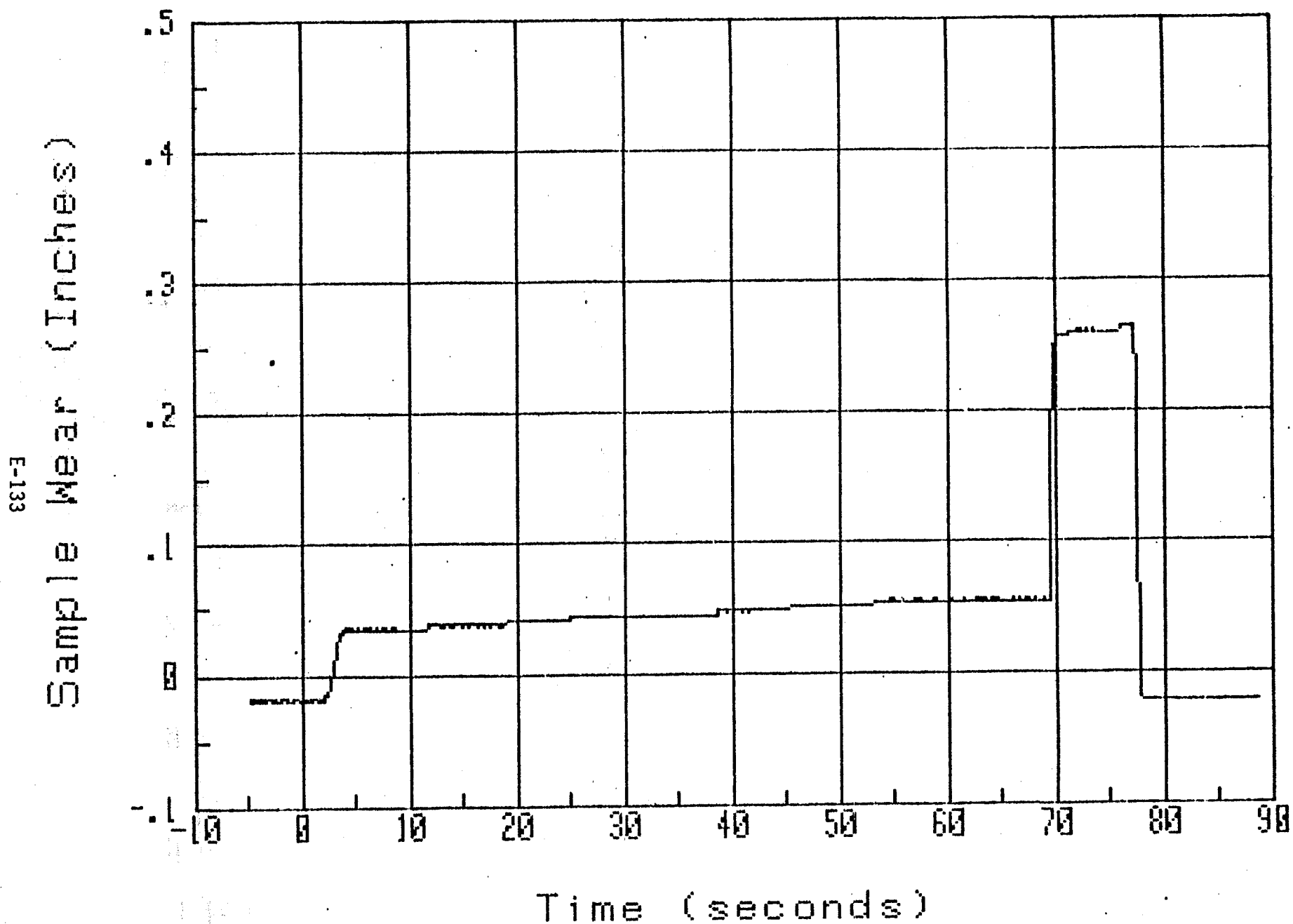


Temperature (°F)

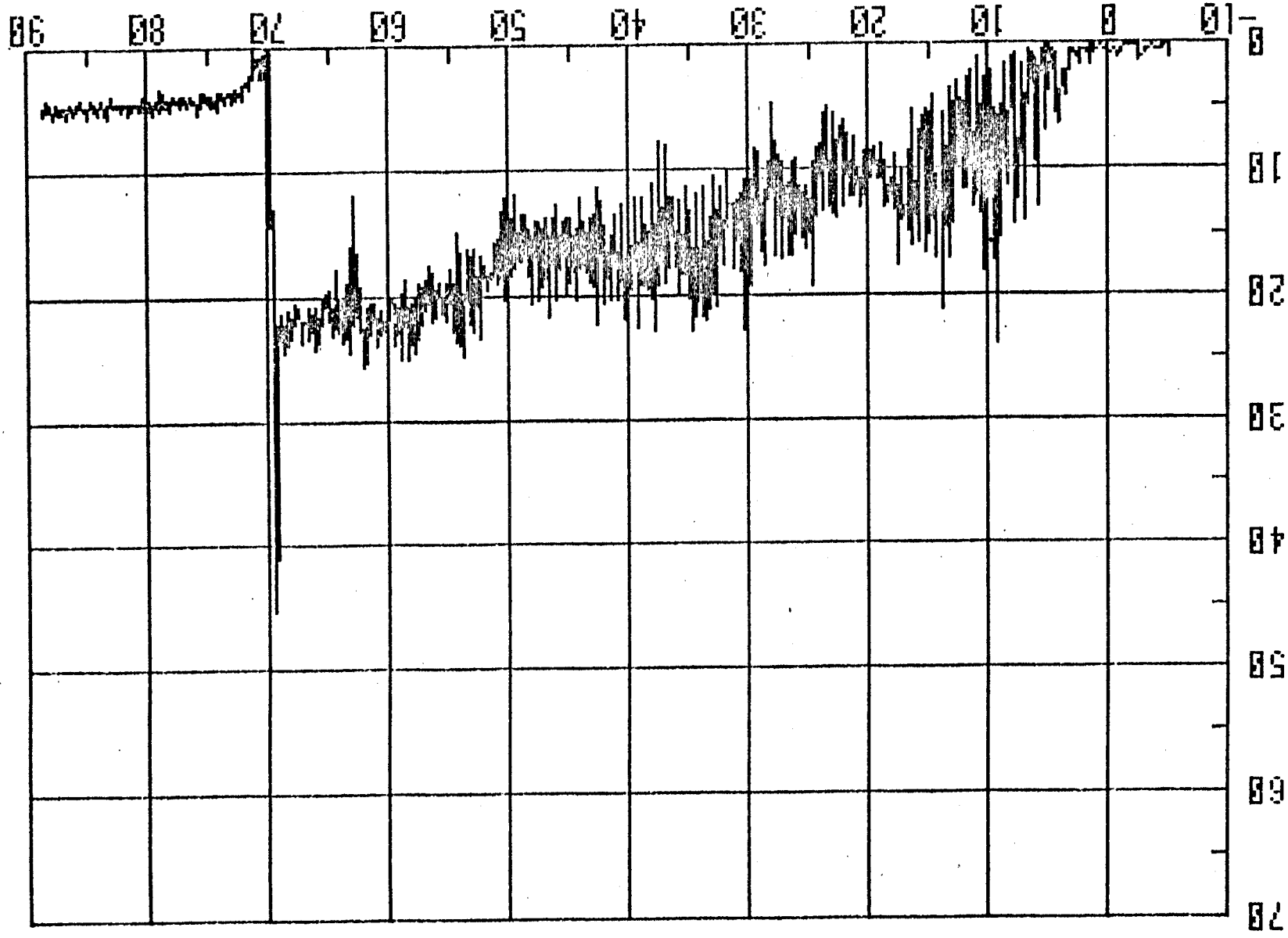
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OF POOR QUALITY

E-132

FRT#273: ElecP1Ni-Stat.; Mon. K500-Rot.



FRT#273: E1ecP1N1-Stat.: Mon. K500-Rot.



Time (seconds)

(197) 0007 anbol

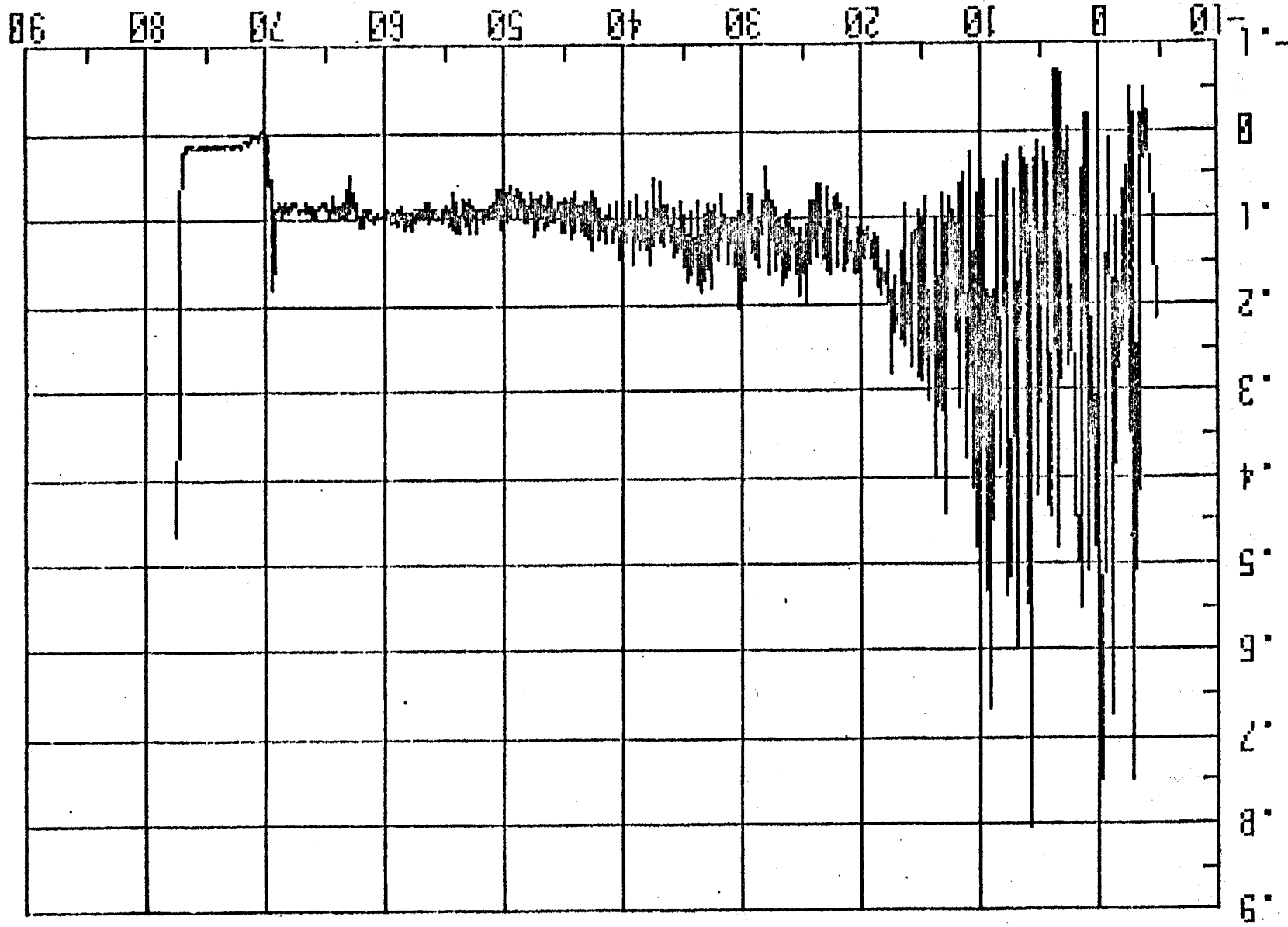
E-134

ORIGINAL PAGE IS
OF POOR QUALITY

Contains a -27.1 load offset.

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OF POOR QUALITY

FRT#273: E1ecPINI-Stat.; Mon. K500-Rot.



Time (seconds)

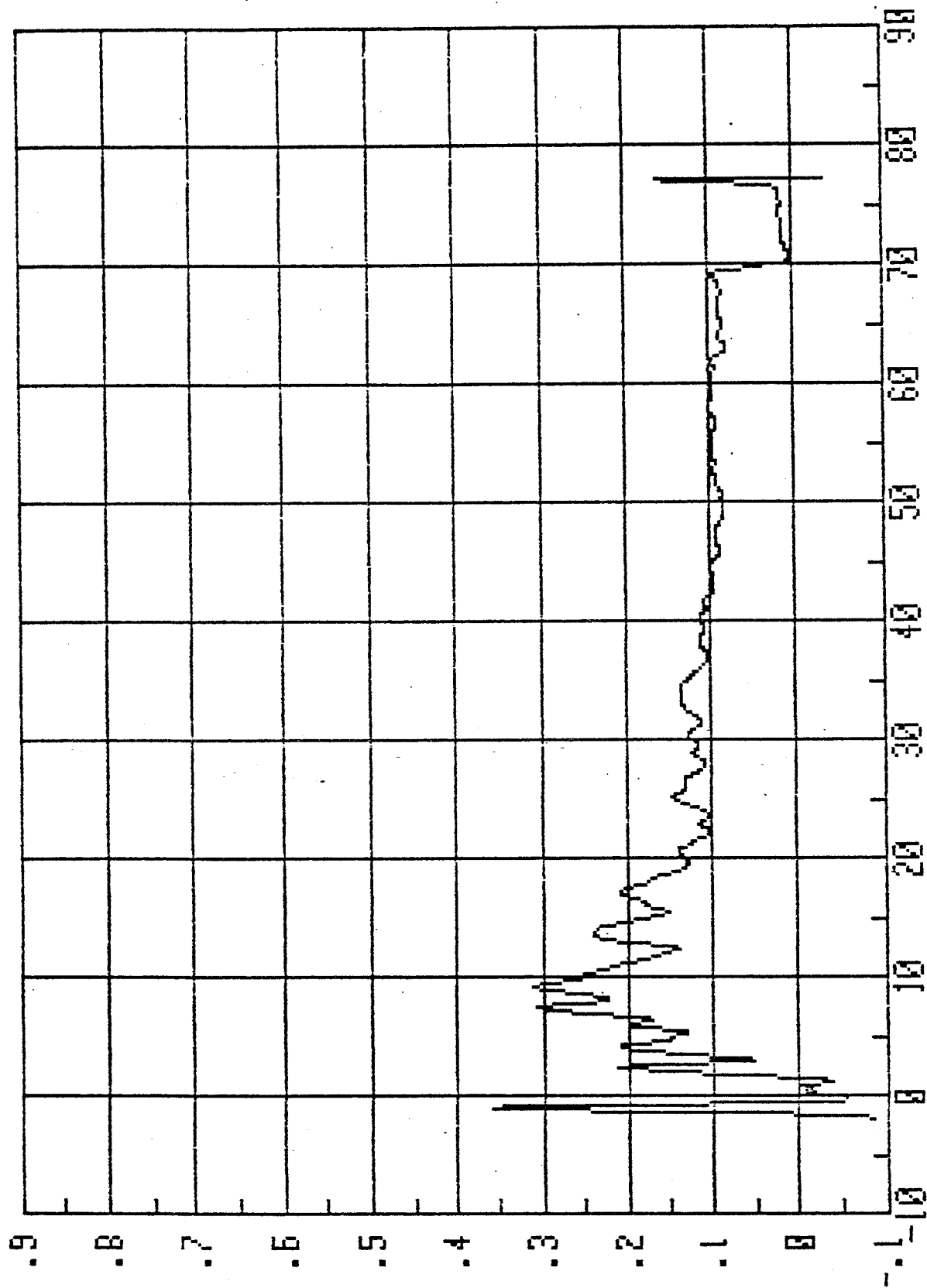
Coefficient of Friction

E-135

Contains a torque load and a normal load offset.

FRT#273: ElecP1Ni-Stat.; Mon. K500-Rot.

Filtered Coefficient of Friction



Time (seconds)

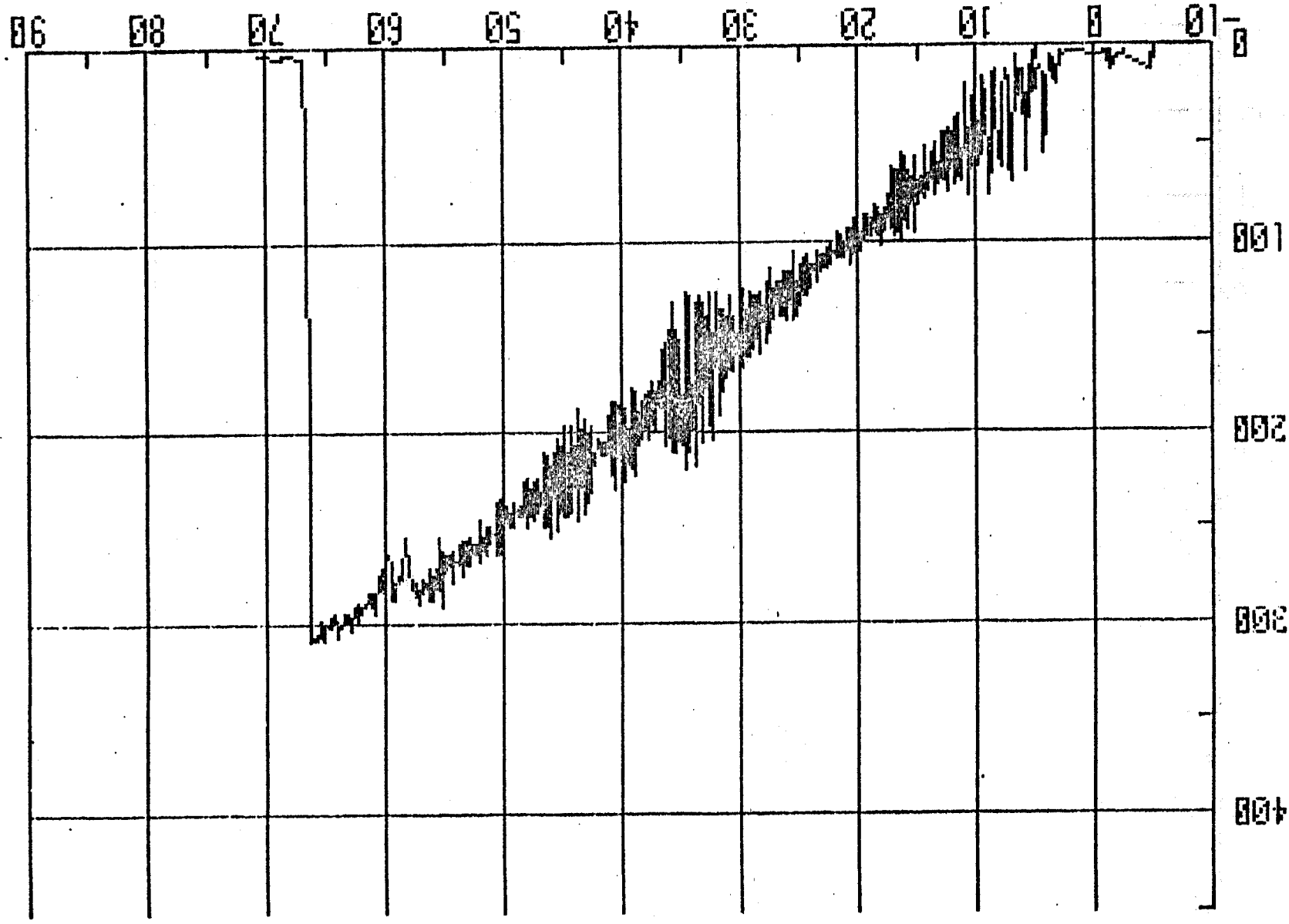
E-136

ORIGINAL PAGE IS
OF POOR QUALITY

Resting = torque load and a normal load offset.

1. *Phragmites australis* (Cav.) Trin. ex Steud.
 2. *Scirpus americanus* (L.) Link.
 3. *Scirpus setaceus* (L.) Link.
 4. *Scirpus robustus* (L.) Link.
 5. *Scirpus tabernaemontani* (Cav.) Trin. ex Steud.
 6. *Scirpus torreyana* (L.) Link.
 7. *Scirpus yagara* (L.) Link.
 8. *Scirpus yagara* (L.) Link.
 9. *Scirpus yagara* (L.) Link.
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 98. *Scirpus yagara* (L.) Link.
 99. *Scirpus yagara* (L.) Link.
 100. *Scirpus yagara* (L.) Link.

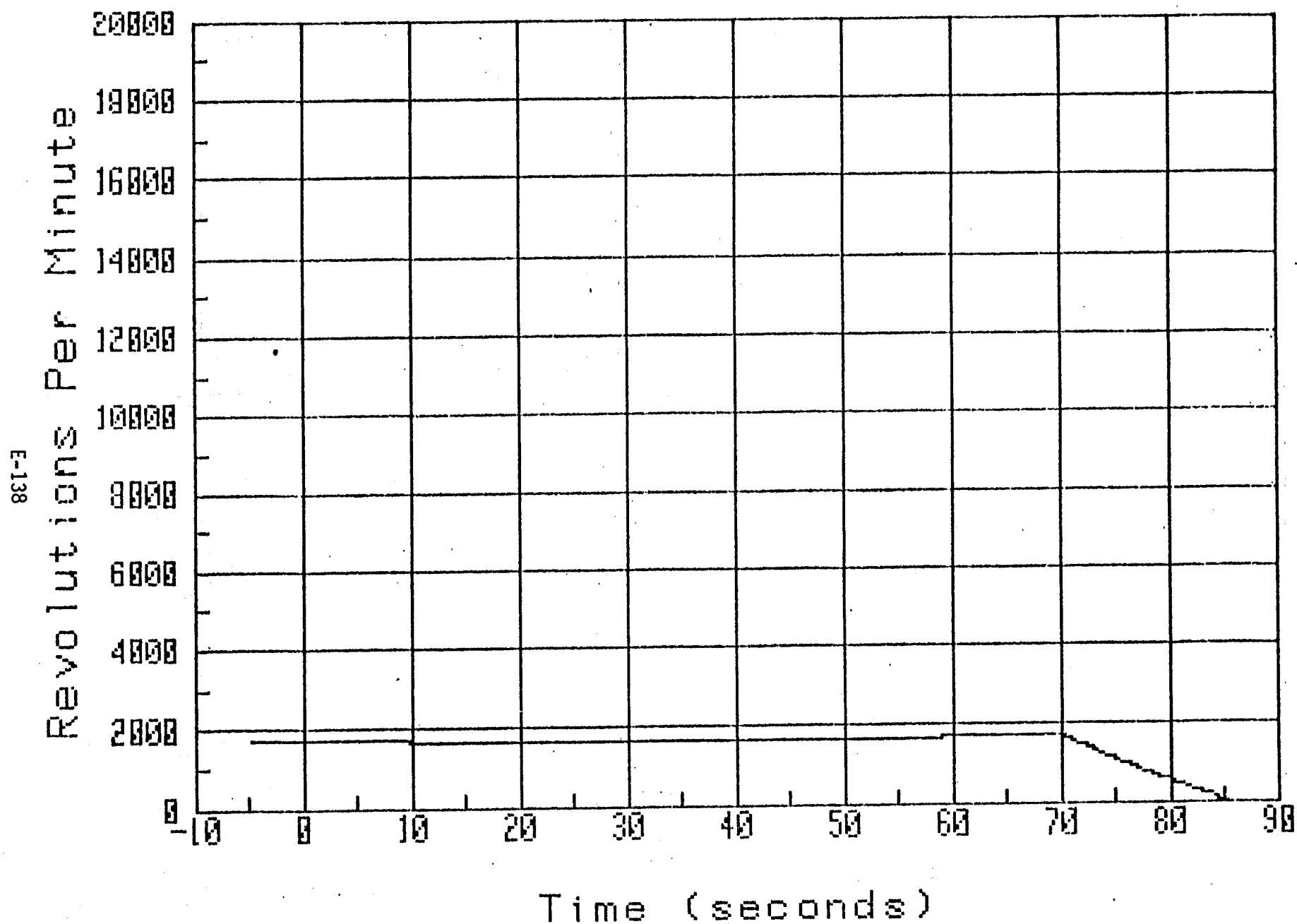
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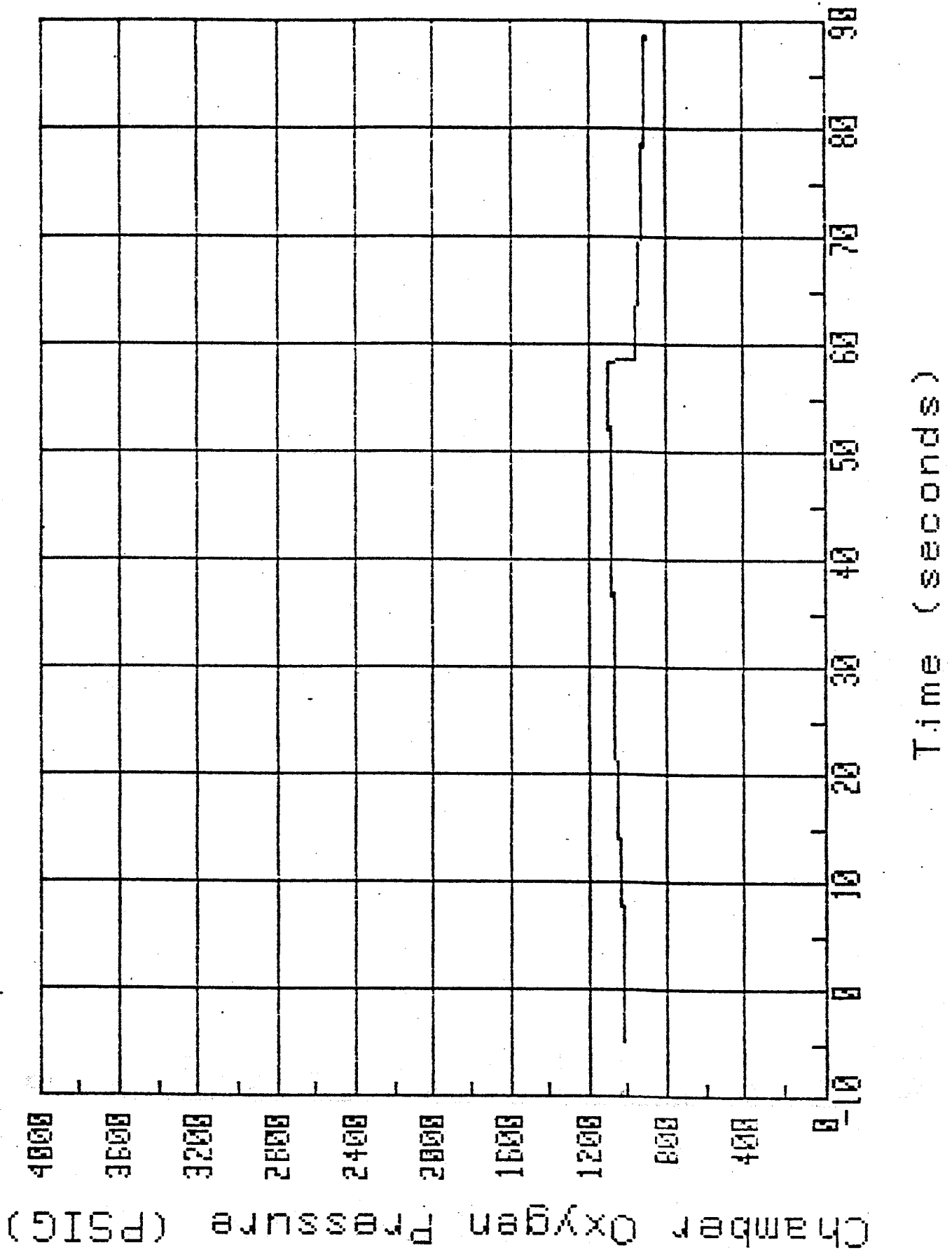
Normal Load (Lbf)

E-137

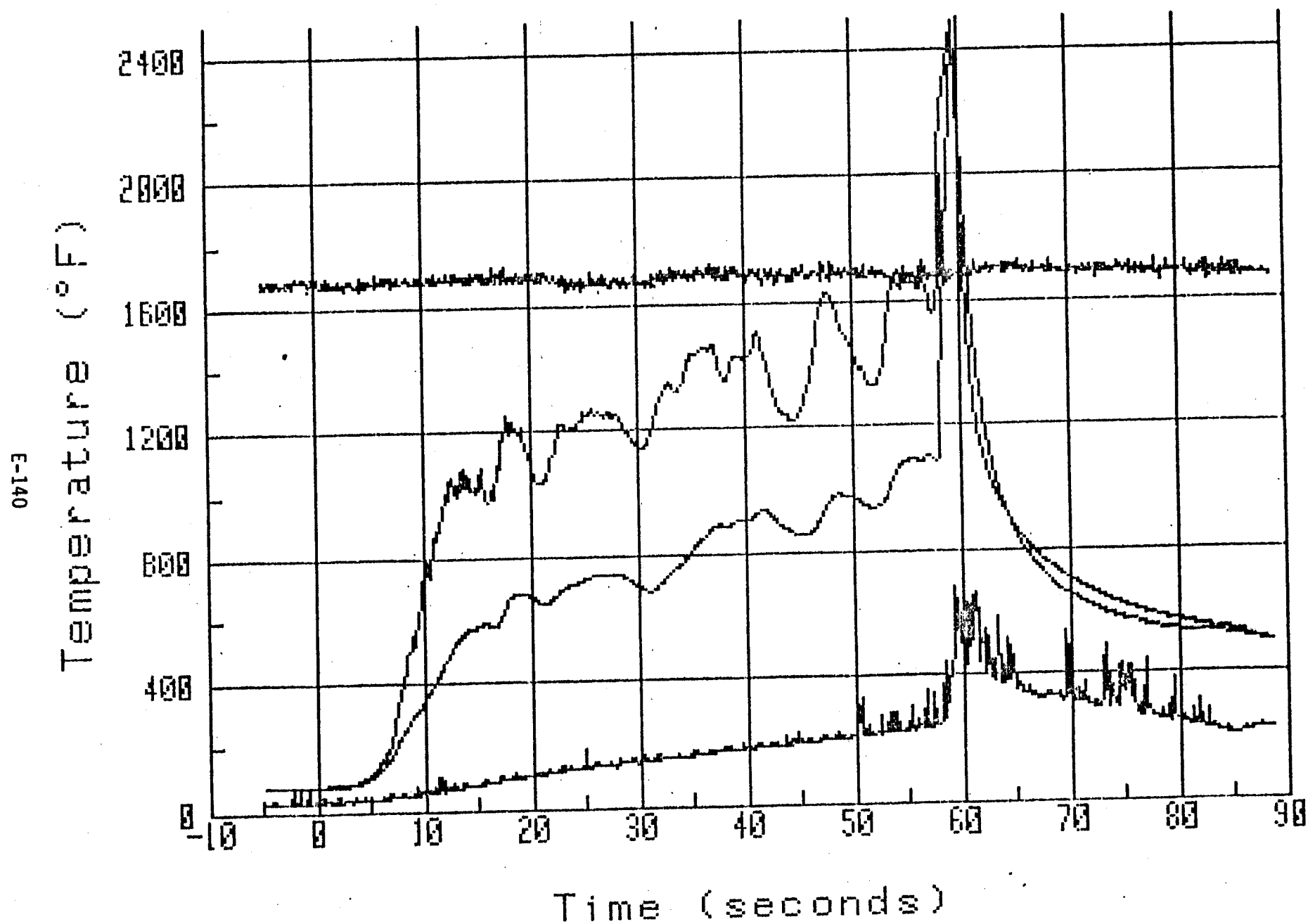
FRT#274: ElecP1Ni-Stat.; Mon. K500-Rot.



FRT#274: ElecP1Ni-Stat.; Mon. K500-Rot.

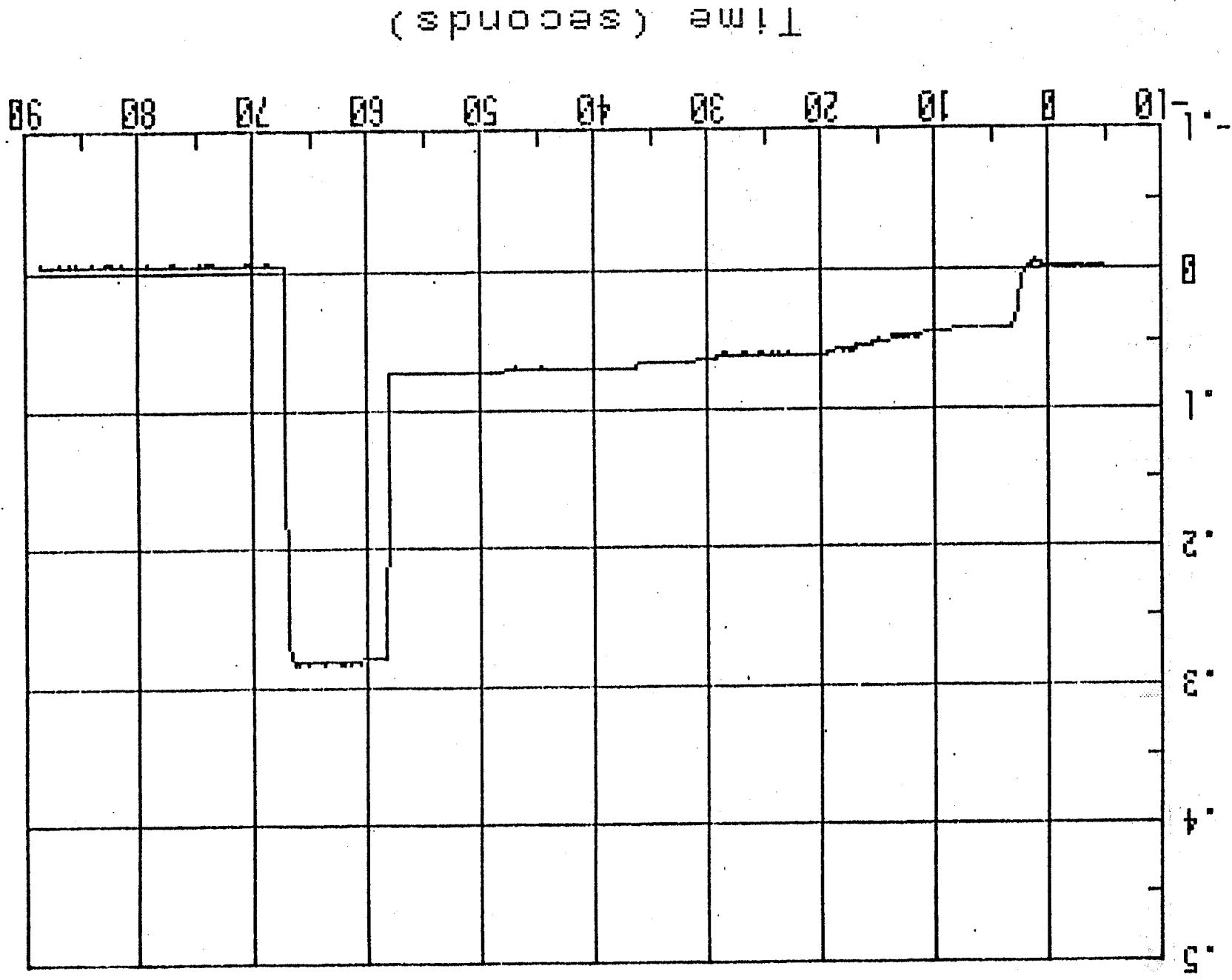


FRT#274: ElecP1Ni-Stat.; Mon. K500-Rot.



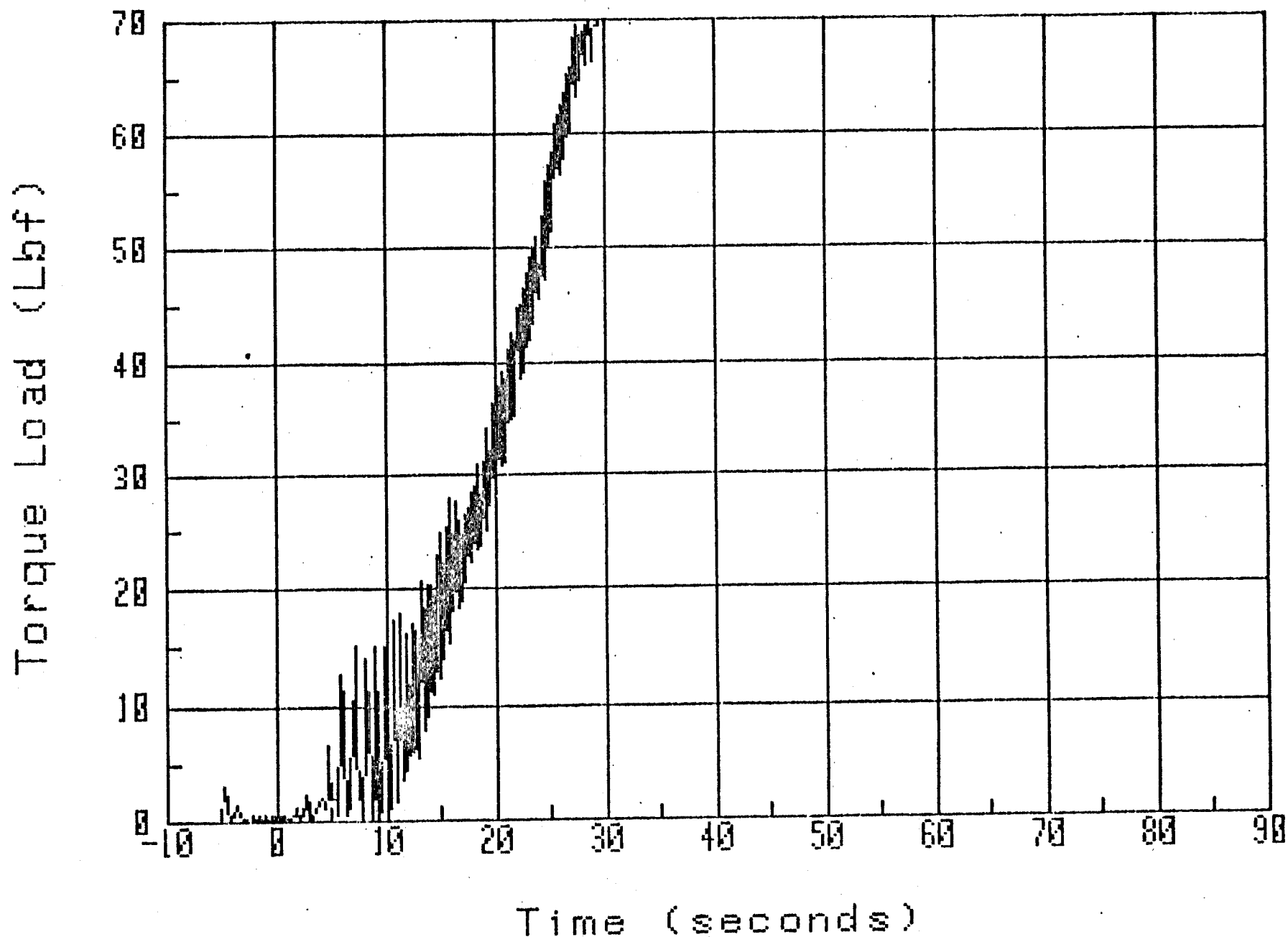
E-141

Sample Wear (Inches)



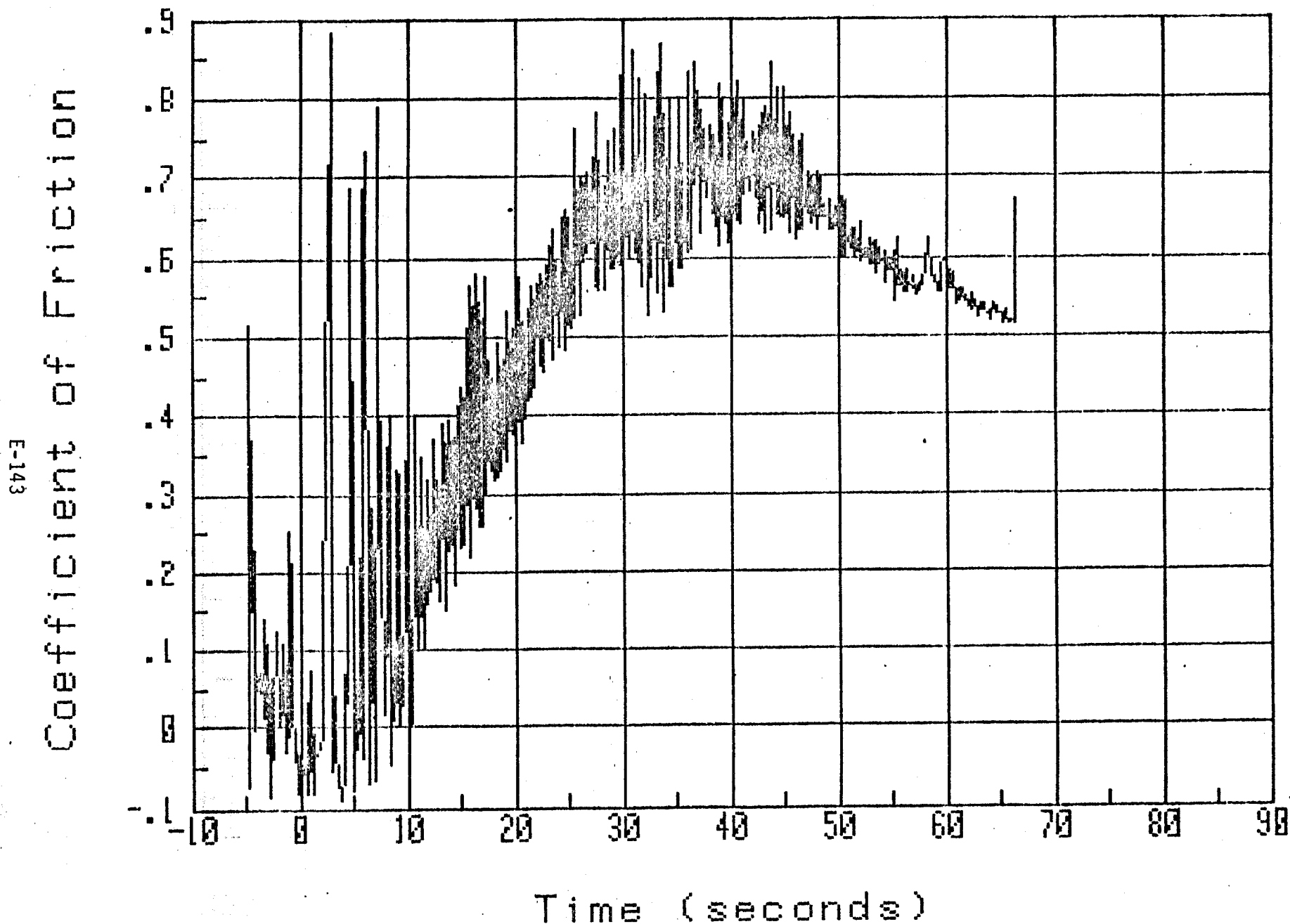
FRT#274: ElecP1N1-Stat.; Mon. K500-Rot.

FRT#274: ElecP1Ni-Stat.; Mon. K500-Rot.



Contains a -20.0 load offset.

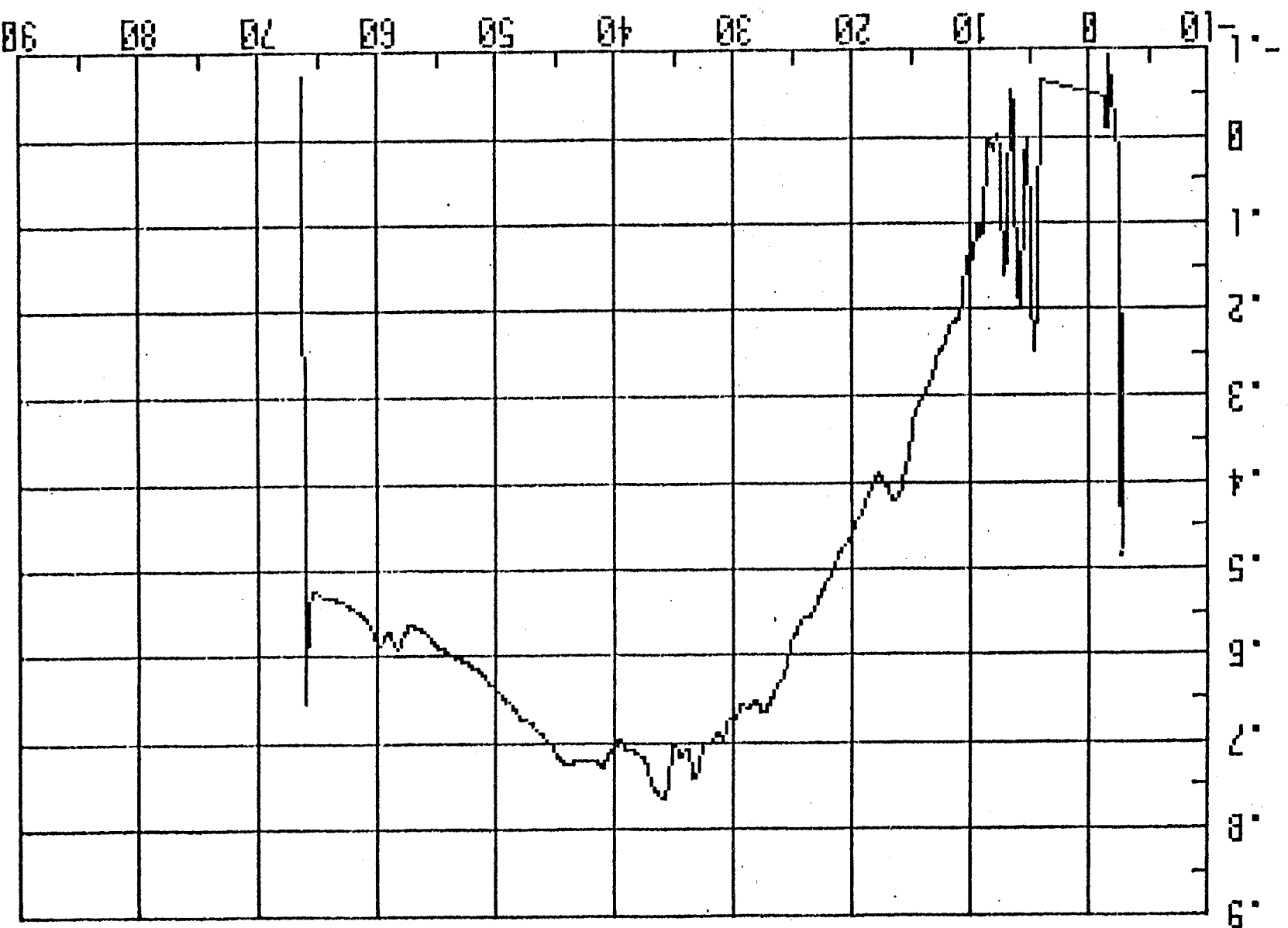
FRT#274: ElecP1Ni-Stat.; Mon. K500-Rot.



Contains a torque load and a normal load offset.

Filtered Coefficient of Friction

Contains a torque load and a normal load offset.



FRT#274: E1ecP1N1-Stat.: Mon. K500-Rot.